C. SPECIFICATIONS

TECHNICAL SPECIFICATIONS

TREATED TIMBER PILING

Treated piling shall be either "Dense" Southern Yellow Pine, Red Oak or Douglas Fir (Coast Region).

All treated piles shall have the rough bark and inner bark removed before treatment.

All wood piling shall be cut from sound, solid, live timber. They shall contain no ring shakes, dote or unsound knots. Sounds knot will be permitted, provided the diameter of the knot does not exceed four (4) inches or one-third (1/3) of the diameter of the stick at the point where it occurs. Any defects or combination of defects which will impair the strength of the pile shall not be permitted. The butts shall be sawed square and the tips shall be sawed square or tapered to a point not less than four (4) inches square. The slope of the spiral grain, if present, shall not exceed one (1) inch in twelve (12).

Piles shall be cut above the ground swell, shall be free from short bends and shall have a uniform taper from butt to tip. A line drawn from center of butt to center of tip shall not fall outside the center of the pile at any point more than one (1) per cent of the length of the pile. All knots shall be trimmed off flush with the body of the pile.

Dimensions

Piles, after peeling, shall have a minimum diameter as shown below unless otherwise required by the Engineer.

The diameter of the tip shall be at least:

	Tip Diameter
Less than 40 feet....................	8 inches
40 to 60 feet	7 inches
Over 60 feet	6 inches

The minimum diameter in inches of the piles at a section four (4) feet from the butt measured under the bark shall be as follows:

Length of Pile	Fir, Pine	All other species
Less than 20 feet	11	11
20 to 30 feet	12	12
31 to 40 feet	12	13
Over 40 feet	13	14

The diameter of the piles at the butt shall not exceed twenty (20) inches.

Treatment

The treatment shall conform to the requirements of the Indiana State Highway Commission's specifications for Preservative Oils and Treatment.

Bridge Flooring

The flooring for this bridge shall be of Armco patented metal flooring or its equal. The plans for said floor are shown on the complete bridge plans attached herewith.

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Forms for Concrete

Forms shall be so designed and constructed that they may be removed without injury to the concrete.

The material to be used in the forms for exposed surfaces shall be sized and dressed, tongue and groove or ship-lap lumber, or metal in which all bolts and rivet heads are countersunk so that in either case a plain smooth surface of the desired contour is obtained. Undressed lumber may be used for backing or for surfaces which will not be exposed in the finished structure. All lumber shall be free from know holes, loose knots, cracks, splits, warps or other defects affecting its strength or the appearance of the finished structure. When possible, forms shall be daylighted at intervals of not greater than ten (10) feet vertically, the openings being of sufficient size to permit free access to the forms for the purpose of inspecting, working and spading the concrete.

The forms shall be built true to line, securely tied together by means of wire or rods and braced in a substantial and unyielding manner. They shall be mortar-right and if necessary to close cracks due to shrinkage, shall be thoroughly soaked with water. Forms for re-entrant angles shall be chamfered and for corners shall be filleted. Dimensions affecting the construction of subsequent portions of the work shall be carefully checked after the forms are erected and before any concrete is placed. The interior surfaces of the forms shall be adequately oiled with paraffin oil as soon as erected to insure nonadhesion of the mortar. Form lumber which is to be used a second time shall be free from bulge or warp and shall be thoroughly cleaned. The forms will be inspected by the Engineer immediately preceding the placing of the concrete and any bulging or warping shall be corrected and all dirt, shavings, sawdust or other debris within the forms shall be removed.

In designing forms and centering, the concrete shall be treated as a liquid weighing one hundred fifty (150) pounds per cubic foot for vertical loads and not less than seventy-five (75) pounds per cubic foot for horizontal pressure. Unit stresses in timber shall not exceed the following:

Douglas fir, white oak and long leaf yellow pine:
- Bending, 1,800 pounds per square inch.
- Columns, 1,800 (1-L/60D) pounds per square inch.

Spruce, cypress, short leaf yellow pine, white pine and western hemlock:
- Bending, 1,500 pounds per square inch.
- Columns, 1,500 (1-L/60D) pounds per square inch.

Where L Length of column in inches and D equals least diameter of column in inches.

Spreader blocks and bracing shall be removed from the forms and in no case shall any portion of the wood forms be left in the concrete. Special attention shall be paid to the ties and bracings, and where the forms appear to be insufficiently braced or unsatisfactorily built, either before or during the placing of the concrete, the Engineer may order the work to be stopped until the defects have been corrected to his satisfaction. The forms shall be so constructed that the finished concrete shall be of the form and dimensions shown on the plans and true to line and grade.

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Sealed proposals will be received by the Board of County Commissioners of Monroe County, Indiana, on the ____ day of ______, 1954, at ________ a.m. at which time the bids will be publicly opened and read, for the following described work.

The bids will then be submitted to the County Commissioners for examination and comparison, and on the completion of this examination as to the amount of the different bids, and the character and sufficiency of the materials offered, the Board will then, if it so elects or chooses, award the contract or contracts for the whole or part of the work and materials to the lowest and best bidder, the Board expressly reserves the right to reject any and all bids and to judge the character and sufficiency of the materials offered.

Permission will not be given for the withdrawal or notification of any proposal after the same has been filed.

Each proposal shall be endorsed with the title of the work, and the name of the bidder, and the date of its presentation. All bids shall be filed with the County Auditor on or before the day and hour mentioned above or before and stated in the advertisement, and no proposal presented after that time will be accepted.

All bids must be on the form which follows: It is understood that all provisions of Bid Form 95 (Revised 1943) as prescribed by the State Board of Accounts are to be considered to be a part of the bid form which follows with such additions incorporated as may be found necessary for this project. The usual statutory affidavit shall be made on the Bid Form.

Each bid must be accompanied by a bond executed by the bidder and surety satisfactory to the Board of County Commissioners, in the sum of ______ percent of the aggregate amount of the bid or proposal; or the bidder may deposit with the Board in lieu of such bond, a certified check on a solvent bank, payable to Monroe County, Indiana, equal to the amount of the required bond. The certified check is required as guarantee that, should the bid or proposal to be accepted by the Board, the bidder will within ten (10) days from the time he is notified of the acceptance of the same, enter into a contract with Monroe County, Indiana, for the work and materials bid upon, and give bond with surety, to be approved by the Board of County Commissioners, insuring faithful completion of the Contract.

In case the bid or proposal is not accepted, the obligation of said bond shall be null and void and said certified check shall be returned to the bidder, however, in case the bid or proposal is accepted and the bidder does enter into a contract with Monroe County, Indiana, for the work and materials bid upon, within ten (10) days from the time he shall have been notified of the acceptance of the same and furnish contract bond as required, then the oblication of the bond shall be null and void and said certified check shall be returned to the bidder.

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The bids will then be submitted to the County Commissioners for examination and comparison, and on the completion of this examination as to the amount of the different bids, and the character and sufficiency of the materials offered, the Board will then, if it so elects or chooses, award the contract or contracts for the whole or part of the work and materials to the lowest and best bidder, the Board expressly reserves the right to reject any and all bids and to judge the character and sufficiency of the materials offered.

Permission will not be given for the withdrawal or notification of any proposal after the same has been filed.

Each proposal shall be endorsed with the title of the work, and the name of the bidder, and the date of its presentation. All bids shall be filed with the County Auditor on or before the day and hour mentioned above or before and stated in the advertisement, and no proposal presented after that time will be accepted.

All bids must be on the form which follows: It is understood that all provisions of Bid Form 95 (Revised 1943) as prescribed by the State Board of Accounts are to be considered to be a part of the bid form which follows with such additions incorporated as may be found necessary for this project. The usual statutory affidavit shall be made on the Bid Form.

Each bid must be accompanied by a bond executed by the bidder and surety satisfactory to the Board of County Commissioners, in the sum of ______ percent of the aggregate amount of the bid or proposal; or the bidder may deposit with the Board in lieu of such bond, a certified check on a solvent bank, payable to Monroe County, Indiana, equal to the amount of the required bond. The certified check is required as guarantee that, should the bid or proposal to be accepted by the Board, the bidder will within ten (10) days from the time he is notified of the acceptance of the same, enter into a contract with Monroe County, Indiana, for the work and materials bid upon, and give bond with surety, to be approved by the Board of County Commissioners, insuring faithful completion of the Contract.

In case the bid or proposal is not accepted, the obligation of said bond shall be null and void and said certified check shall be returned to the bidder, however, in case the bid or proposal is accepted and the bidder does enter into a contract with Monroe County, Indiana, for the work and materials bid upon, within ten (10) days from the time he shall have been notified of the acceptance of the same and furnish contract bond as required, then the oblication of the bond shall be null and void and said certified check shall be returned to the bidder.

Sealed proposals will be received by the Board of County Commissioners of Monroe County, Indiana, on the ____ day of ______, 1954, at ________ a.m. at which time the bids will be publicly opened and read, for the following described work.

The bids will then be submitted to the County Commissioners for examination and comparison, and on the completion of this examination as to the amount of the different bids, and the character and sufficiency of the materials offered, the Board will then, if it so elects or chooses, award the contract or contracts for the whole or part of the work and materials to the lowest and best bidder, the Board expressly reserves the right to reject any and all bids and to judge the character and sufficiency of the materials offered.

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Sealed proposals will be received by the Board of County Commissioners of Monroe County, Indiana, on the ____ day of ________, 19__, at ________ a.m. at which time the bids will be publicly opened and read, for the following described work.

The bids will then be submitted to the County Commissioners for examination and comparison, and on the completion of this examination as to the amount of the different bids, and the character and sufficiency of the materials offered, the Board will then, if it so elects or chooses, award the contract or contracts for the whole or part of the work and materials to the lowest and best bidder, the Board expressly reserves the right to reject any and all bids and to judge the character and sufficiency of the materials offered.

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In accordance with the provisions of the Acts of the General Assembly of the State of Indiana, Chapter 306, Acts of 1947, each bidder will be required to submit under oath, with and as a part of his bid, a statement of his experience, his proposed plan for performing the work, the equipment which he has available for the performance of the work, and a financial statement of his business. These statements must be sumitted on forms prescribed by the State Board of Accounts, and may be acquired by from the County Auditor. The above requirements are confined to bids of $5000.00 or over.

The successful bidder at the time of signing the contract will be required at his own e xpense to furnish bond guaranteeing faithful execution of the contract in full amount of the contract price, executed by the bidder and surety to be approved by the Board on the bond form marked "Performance Bond" and bound herewith. The performance bond shall contain the following clauses: "The surety for value received hereby stipulates and agrees that no chance or extension of time, alteration or additions to the terms of the contract or the work to be performed thereunder, or to the specifications accompanying the same shall in anywise effect its obligations on this bond, and it does hereby waive notice of any such change, extension of time, alteration or addition to terms on the contract, or to the work or to the specifications.

The successful bidder of this work will be required to pay and to require that any sub-contractor pay wage rates which shall not be less than the prescribed scale of wages required by law. In other words, the wages paid on any of this work shall not be less than the prevailing wage scale for this area.

Where, in these specifications or on the plans, one or more certain materials, trade name or article of certain manufacture are mentioned it is done for the sole purpose of establishing a basis of durability and efficiency and not for the purpose of restricting competition.

The bidders are required to visit the site and to inform themselves fully of conditions relative to the construction and labor under which the work will be done.

The County Auditor will inform each bidder, upon request, as to the amount and kind of insurance required by the County for this construction. The bidders likewise will be given full information concerning the amount and kind of bonds required by the County, in case these specifications are not clear to any bidder.

Preference shall be given to qualified local residents in the employment of labor and mechanics for work on the projects under this contract. No person under the age of 16 years shall be employed on the project covered by these specifications.

There shall be no discrimination by reason of race, creed, color or political affiliations (except Communists - who shall not be employed) in the employment of person or persons for work on the project covered by these specifications, who are qualified by training and experience for such work; however, all persons employed on this work must be citizens of the United States of America.

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Nothing in this contract shall create contractual relations between the sub-contractor and the Board of County Commissioners.

The work shall be started at the time stated in the notices to the Contractor to proceed and shall be completed in _____ consecutive calendar days from and after the date stated in said notice.

The Contractor shall hold Monroe County, Indiana, free from any losses, damages, injuries or infringements due to the work covered by these specifications.

The word "Board" as used in these specifications, proposal and contract refers in every case to the Board of Monroe County, Indiana, Commissioners at Bloomington, Indiana.

The word "Contractors" as used in these specifications or the contract refers in every case to the person, firm or corporation or co-partnership who has entered into a contract to carry out the provisions of these specifications and plans for the work covered by the same.

No omission of any detail from the specifications or drawings shall release the Contractor from furnishing any materials or item of equipment usual or proper/from doing anything necessary for the proper, complete construction.

The Contractor shall keep a copy of these specifications and plans of his work on the site of his work at all times.

Unless otherwise stipulated in the plans and specifications, all materials, equipment and articles incorporated in the work covered by these plans and specifications shall be new and of the best grade of their prospective kinds, and shall be furnished by the Contractor along with necessary labor.

The Contractor will be responsible for any damage to the existing structure and adjacent structures to the project, or to this work already finished. All used or old material or materials, now in place shall be salvaged by the Contractor and stored in neat piles out of danger to the public in any way, and the Contractor shall be responsible for the same until it is removed by the County Highway Department or until the acceptance of his work.

If any defect or failure on account of defective material or workmanship shall appear within one (1) year from the date of acceptance, the same shall be replaced or made good by the Contractor without cost of Monroe County, Indiana.

Payment for the work under this contract will be made on a lump sum basis after final acceptance of the work.

The Contractor shall at all times, keep the premises free from accumulation of waste materials or rubbish caused by his employees or work, and at the completion of the work, he shall remove all rubbish and surplus materials and leave the work and the site clean and ready for use.

Monroe County, Indiana, shall not be held responsible and will not replace or make good any damages caused by storms, floods or any other act of God, however, the Contractor shall repair or replace any damages caused by the above mentioned causes.

Contractor shall furnish all materials required, shall furnish all necessary transportation, tools, a competent supervisor and all skilled and unskilled labor necessary to install and complete the work described on page one (1) of these specifications.

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C O N C R E T E

1. Kinds of Cementing Materials. ____ A material which by proper treatment can be made plastic and which will then gradually harden to form a solid mass is called a cementing material. Most cementing materials become plastic when water is added to them, and then harden because of a chemical process. Portland Cement, which is the cementing material used most extensively in construction, is in this class. Other materials in this class that are used in construction are natural cements, high-alumina cements, limes, plaster cements, and puzzolanic, or slag, cements. Bituminous, or asphaltic, cements become plastic when heated and harden on cooling. They are used mainly as binders in road construction and in the preparation of waterproofing paint. The particles of cemanting materials not only cohere to each other on hardening, but also adhere to other materials with which they are in contact and, therefore, cementing materials can be used to bind bodies together.

2. Mortar. ____ A mixture of sand and a cementing material in proper proportions and in a plastic state is called mortar. In hardening, the cementing material binds together the particles of sand and forms a solid mass. Mortar also adheres to other larger bodies between which it is placed and these bodies can, therefore, be bonded by the mortar. Thus, bricks or stones are bound together in a wall by laying mortar between them.

3. Concrete. ____ If pieces of broken stone, gravel, cinders, or slag are mixed with a mortar of sand, cement, and water, concrete is formed. When freshly mixed, concrete can be poured into molds or forms, and on hardening will take shape in the mold. Concrete is extensively used in all kinds of construction; when used in combination with steel rods, it is known as reinforced concrete.

4. Aggregates. ____ The inert material which is bound together by the cement in concrete is called aggregate. The part of the aggregate which is less than ¼ inch in size is generally called the fine aggregate and usually includes only the sand. The remainder of the aggregate is called the coarse aggregate. The maximum size of the coarse aggregate in ordinary concrete work is 3 inches.

5. Setting of Cement. ____ When water is added to cement, a paste is formed which remains plastic for a time and then, if undisturbed, begins to lose its plasticity, or to set; finally, it becomes rigid. The chemical changes that take place in the cement when water is added are not thoroughly understood, but it is known that the action of the water on the cement results in the formation of both crystalline and jelly-like products. These products adhere to each other and to surfaces in contact with them and eventually become very hard. If the materials are kept moist, the chemical reactions may continue for years and the structure may gain in strength over a long period of time. In order that cement in mortar or concrete may harden properly, it is important that the correct amount of water be used and the materials be mixed and handled in the right manner. During the early stages of the setting process, the product may be disturbed without being injured, but after the reactions have reached a certain stage, the strength of the product is seriously impaired by disturbing the particles of cement. It is very helpful in construction that the hardening process does not start until sufficient timehas elapsed to permit the thorough mixing of mortar or concrete, the transportation of the mixture from the mixer to forms, and the proper placing of it in the forms.

Under certain conditions cement may have a very quick set, or so-called <u>flash set</u>. Such cment cannot be used for ordinary purposes because concrete made with quick-setting cement cannot be mixed and placed properly. In the setting of cement, two stages are reconized: First, the initial set, when the paste begins to harden, or to offer restistance to change of form; and, second, the final set, when the setting is complete, or when the mass cannot be appreciably distorted without rupture.

6. Reasons for Fineness Test. ____ The fineness of cement is important because it affects both the strength and the soundness of the product. The more finely a cement is ground, the more thoroughly will the cement paste cover the particles of sand, and hence the greater will be the strength of the resulting mixture. Moreover, as the fine particles are more quickly acted on by the mixing water, the crystallization is hastened. Therefore, not only the ultimate strength of the product but also the early strength is increased. Fineness of grinding affects the soundness of cement because the expansive elements contained in the coarse particles are not readily susceptible to the action of seasoning, which will hydrate and render inert the unsound material in the fine particles.

7. Definitions: ______ The strength and other properties of hardened cement paste, mortar, or concrete vary considerably with the percentage of water used in mixing, that is, with the consistency of the frest mixture, which is a term employed to express the degree of plasticity of the mixture. In order to provide a basis for comparision, when cement is tested it is essential that the amount of water used in preparing the paste or mortar for the test should be such as to bring the plastic mixture to a standard physical condition. This condition is called normal consistency. Different cements require different per cents of water to make a specimen of normal consistency because of their varying chemical composition, degree of burnigg, fineness, age, etc.

8. Approximate Test. ___ An approximate and convenient method for determining normal consistency is to form the paste into a ball about 2 inches in diameter and to drop this ball on a metal slab or glass plate from a height of about 2 feet. If the cement is of the correct consistencey, the ball will not crack nor will it flatten to less than half its original diameter.

9. Purpose of Test. ____ The test for time of setting is made to determine whether or not the cement will become hard at the time most desirable in actual construction. If it begins to set too soon, the crystallization of the particles will begin before the mortar or concrete is thoroughly tamped into place and further working of the mixture will tend to break up the crystals and to weaken the product. If, on the other hand, the cement sets too slowly, the material is more likely to suffer from exposure to heat, cold, or inclement weather; also, the progress of the work will be much delayed on account of the greater interval required between placing different sections, and the longer time the forms must be left in place. As the time of setting varies considerably with the amount of mixing water used, it is essential that every sample tested be brought exactly to normal consistency. The time of setting is also very appreciably affected by variations in the temperature and humidity of the air in which the test peices are kept during the period of setting, by the temperature of the mixing water, and the amonnt of kneading that the paste ~~######~~ receives. Standard practice requires that both the materials and the room in which the tests are made be at a tempertture of as near 21 degrees centigrade as practicable. Two froms of apparatus are used to test the time of setting, namely, the Vicat needle and the Gillmore needles. In either case, the times are determined for both initial set and final set.

10. <u>Specifications for Time of Setting.</u> — The standard specifications stipulate that portland cement shall show initial set in not less than 60 minutes when the Gillmore needle is used, and shall develop final set in not more than 10 hours. It must be remembered that cement, mixed with an aggregate and with an excess of water in the field, will require from two to four times as long to set as the cement paste mixed with little water in the laboratory. Cement, therefore, showing an initial set at the expiration of 45 minutes with the Vicat needle or 60 minutes with the Gillmore needles, will generally not begin to set in actual concrete construction work in less than $1\frac{1}{2}$ hours, which gives ample time for mixing and placing the materials; and cement setting in less than 10 hours by the test, will usually be quite hard in the work in 24 or, at most, in 36 hours, although the forms must be left in place on the work for a much longer time in order to obtain the required strength.

11. <u>Soundness and Seasoning.</u> — Soundness may be defined as the ability of cement to resist disintergration. Although a cement may at first show sufficient strength, it is dangerous to use it for construction purposes if there is a possibility of later disintergration. The most common cause of unsoundness in portland cement is an excess of free or uncombined lime, which crystallizes with great increase of volume and thus breaks up and destroys the bond of cement. This excess of lime may be due to incorrect proportioning, or to insufficient grinding of the raw materials, to underburning, or to failure to store for a sufficient length of time before use, such storing being called seasoning. A certain amount of seasoning is usually necessary, because almost every cement, no matter how well proportioned or burned it may be, will contain a small excess of lime which, when exposed to air, will absorb moisture and become inert.

12. <u>Classification of Limes.</u> — The two broad classes of limes are <u>common lime</u>, commercially dalled <u>quicklime</u>, and <u>hydraulic lime</u>.

Quicklimes are classified, according to their chemical composition, as follows: (a) high-calcium lime, containing at least 90 per cent. of calcium oxide; (b) calcium lime, containing from 85 to 90 per cent calcium oxide; (c) magnesium lime, containing from 85 to 90 per cent. calcium and magnesium oxide, of which 10 to 25 per cent. is magnesium oxide; (d) high-magnesium lime, containing not less than 85 per cent. calcium and magnesuim oxide, not less than 25 per cent. being magnesium oxide. Magnesium lime is also called dolomitic lime. There are two grades of quicklime, namely, selectedlime, which is well burned lime picked free from ashes , pieces of flint, clinker, and other foreign material; and run-of-kiln lime, which is a well burned lime without selection. Quicklime is shipped either as lump lime, the particles of which are of the sizes that come from the kiln, or pulverized lime, the particles of which are reduced to sized that will pass a $\frac{1}{4}$ inch screen. There is also marketed what is called hydrated lime which is a fine dry powder resulting from the treatment of quicklime with water. Lump lime is usually sold in barrels of which there are two sizes. One size has a nominal weight of 200 pounds and a net weight of 185 pounds, and the other a nominal weight of 300 pounds and a net weight of 280 pounds. Loose material weighs 50 to 60 pounds ~~and a net weight of 280 pounds~~ per cubic foot or 75 to 80 pounds per bushel. Hydraulic lime contains such a large percentage of silicate, aluminate, or ferrate of lime that it will harden under water, usually in from 1 to 40 days. At the same time it contains so much calcium oxide that it will slake like quicklime when mixed with water. It is seldom used in the United States.

13. Slaking Lime. ___ When water is added to quicklime, a violent action, called slaking or slacking, occurs. The lumps break up, heat is generated, and a product, calcium hydroxide, is formed, which has an entirely different character from the original quicklime. Slaking is therefore a chemical process. When used in construction work, the lime is spread in a shallow, water-tight, wooden box, or on a wooden platform banked around the edges with sand, or is placed in a shallow bed of sand. The water is then added and the lime is thoroughly mixed with hoes during the slaking action, until uniform consistency of a thick paste is obtained. The product is called lime paste. The small quantity of sand that may enter into the lime during the process is unobjectionable, because a large amount of sand will be added later in making mortar. Enough water should be used and the mass thoroughly mixed so that the water will come in contact with all parts of the lime. If too little water is used or if the mixing is insufficient, some of the lumps become dry and are said to be burned in slaking. Burned lime makes mortar tough and non-plastic. An excess of water causes the slaking to proceed slowly and the resulting paste will be thin and watery. Such lime paste is spoken of as drowned. The amount of water required varies with the properties of the lime. Some high-calcium limes may require as much as 40 gallons of water per 200-pound barrel to produce a paste; but for ordinary conditions the average amount needed to slake high-calcium lime is about 31 gallons per barrel or 1½ pounds of water per pound of lime. The amount of water required to slake a dolomitic lime is considerably less, the maximum amount being about 30 gallons per barrel and the average 24 gallons per barrel or about 1 pound of water per pound of lime. The approximate quantity of water required to complete the slaking of a batch of quicklime should be applied by sprinkling before the mixing is begun. If cold water is added after slaking has commenced, the temperature of the mixture is lowered and the lime is caused to become granular and lumpy.

14. Hydrated Lime. ___ Hydrated lime results from the addition of an exact amount of water to a predetermined exact amount of lime. In producting hydrated lime, an excess quantity of water must be used above that required to combine chemically with the lime, because a certain quantity is driven off as steam by the heat generated in slaking. The quantity of water required is subject to wide variations, since it is dependent upon a number of conditions, such as temperature of the water, the quality of lime, and the dryness of the atmosphere. If too little water is used, some particles of lime will not have access to the water and these will not slake, but will be present in the finished hydrate, causing it to be unsound. Hydrated lime weighs 36 to 45 pounds per cubic foot, or 45 to 56 pounds per bushel. It is commonly sold in 100-pound sacks, having a volume of about 2½ cubic feet. About equal weights of water and hydrated lime are required to make a paste. A 100-pound sack of hydrated lime gives about 2.3 cubic feet of paste of ordinary consistency.

15. <u>Use of Hydrated Lime.</u> — In general, a mortar that is made with hydrated lime and sand alone is not so strong as one made with portland cement and sand alone, but the addition of a limited quantity of hydrated lime to cement mortar does not weaken the mortar. However, an excessive amount of lime reduces the strength. There is considerable diversity of opinion as to the maximum percentage of hydrated lime allowable in portland cement mortar; many engineers maintain that 10 per cent. by weight is the limit. It is claimed that the addition of hydrated lime makes cement mortar more workable so that it can be more easily handled with a mason's trowel, and thus gives better bearing surface to the bricks. A further advantage is said to be increased ability of the lime-cement mortar to hold its moisture against the absorbing action of the bricks. Hydrated lime also makes wet concrete more plastic — more workable, and more readily cast or molded into shape. It gives fresh concrete the slipperiness required to enable it to slide down chutes, without the necessity of using so much water that the strength of the concrete is endangered and without the separation of the mortar from the coarse aggregate. It is claimed to increase the density of concrete, thus increasing the water-tightness and, to some extent, the durability. Steel embedded in concrete is protected by the addition of hydrated lime, because of the increased density and the neutralizing action of the lime on any corrosive acids that may be present. The possibility of underburning, overburning, or underslaking quicklime has led to its being largely replaced by hydrated lime.

16. <u>Hardening of Lime.</u> — Lime hardens by reason of the gradual absorption of carbon dioxide from the air. The carbon dioxide slowly changes ~~to calcium hydrate~~ the lime from the form of calcium hydrate to calcium carbonate, so that the final result is to restore the material to its original condition prior to burning; hardened lime mortar is practically limestone containing sand. To secure this result, however, all parts of the mortar must be readily accessible to dry air. If placed under water or in damp situatians, of if excluded from contact with the air, lime mortars will not harden. Even in the interior of thin building walls of brick laid in lime mortar, the lime will be soft, crumbly, and sometimes even plastic after several years, although the edges of the mortar, where exposed, are perfectly hard. It is chiefly for this reason that lime mortars are no longer employed in important construction work, and have been superseded by cement mortars.

17. <u>Fine Aggregates.</u> — According to the Specifications for Concrete Aggregates of the American Society for Testing Materials, fine aggregate should consist of sand or other approved inert materials with similar characteristics, or a combination thereof, having hard, strong, durable particles. Also, the material must pass a 3/8 inch sieve and must be free from injurious amounts of dust, lumps, soft or flaky particles, shale, alkali, organic matter, or other deleterious substances.

18. Coarse Aggregate. ___ Coarse aggregate should consist of crushed stone, gravel, blast-furnace slag, or other approved inert materials with similar characteristics, or a combination thereof, having hard, strong, durable pieces free from adherent coatings. The material must not contain unjurious amounts of soft, friable, thin, elongated, or laminated pieces, dust, lumps, shale, alkali, organic matter, or other deleterious substances. Not more than 10 per cent. by weight should pass a No. 4 sieve.

19. Sand. ___ The sand for mortar or concrete is usually obtained from natural deposits. It is not essential that the particles of sand be sharp, but the material must be clean and hard and the particles should preferably be graded in size from fine to coarse with the coarser sizeds predominating. When sand is dug from a bank care should be taken to remove all the top soil first. Then, there will be no chance of loam sliding into the pit and mingling with the sand.

20. Stone. ___ The stone used as coarse aggregate is obtained by crushing rock in a rock crusher or by hand. Trap rocks, granites, and hard limesfone and sandstones are satisfactory for use in concrete. Trap rocks, which are of igneous origin, are strong, tough, and durable, and are generally preferred for concrete that is to be subjected to abrasive wear, as in roads. The granites are usually hard and durable and are suitable for high-grade concrete. The limestones and sandstones vary greatly in quality; the hard limestones and compact sandstones make desirable aggregates, but the softer varieties should not be used in first-class concrete. Slate, unless of very solid and durable character, should be used only when no better material can be obtained, as it is subject to disintergration. In, general, differences in the hardness of sound particles of stone will affect the resistance of the concrete to wear but will not have a great influence on its compressive strength, as such particles of stone are considerably stronger than the hardened cement mortar that binds them together. Stone screenings can be used in place of sand, with satisfactory results, if they come from hard, durable rock, such as granite or trap rock, and if they are well graded, clean, and free from an excess of dust.

21. Influence of Aggregates on Quality of Concrete. ___ The strength, density, and general quality of concrete depend to a large extent on the aggregates. Even when the most careful attention is paid to the proportioning of the materials, and to the mixing and placing of the concrete, good results cannot be expected from poor aggregates. ~~Ingenreal~~ In general, the properties of the aggregates that influence the quality of concrete are: (1) the grading, or maximum and comparative sizes, of the particles; (2) the amounts and kinds of impurities in the aggregates; (3) the compressive strength, or resistance to crushing, of the aggregates; (4) the durability of the aggregates, or their resistance to fire exposure, to weathering, and to wear. Before a material is used as an aggregate in concrete, it should be subjected to various tests.

22. Sampling of Sand and Gravel. ___ The two chief sources of supply of sand and gravel are non-commercial deposits and commercial sand and gravel plants. The term non-commercial deposit applies to any undeveloped sand and gravel deposit and also to any developed deposit where the material is not washed or screened. If such a deposit is worked as a bank or pit and has an open face, several samples should be taken by channeling the open face, care being taken not to include any of the material overlying the deposit that has fallen along the face from the top. Also, test pits should be excavated some distance back of and parallel to the face and several samples should be taken from these pits. The samples from the face and pits should be well mixed to from a composite sample. In the case of a non-commercial deposit that has no open face, the samples should be taken from test pits. If the various samples do not show radical differences in size of particles, color, etc., they may be mixed together to from a composite sample. Otherwise, each sample will require separate tests. Where possible, samples of sand should be taken when in a damp condition.

Samples of sand or gravel from commercial screening or washing plants should preferably be taken while the material is being loaded from bins or storage piles. However, if necessary, samples may be taken from a bin or pile or from cars or boats during unloading. Sand or gravel samples should be shipped in a tight box or closely woven bag.

23. Importance of Size and Shape of Particles. ___ When the proportions of water, cement, and aggregates in a concrete or mortar mixture are fixed, the density of the mass and its plasticity or workability are determined in a large degree by the relative sizes of the particles of aggregate and the relative quantity of each size. In general, larger particles produce a more compact mass and there is less surf ace to be coated with cement paste. This is especially true of sand and therefore it is often advisable to ship a coarse sand a considerable distance rather than to use a local fine sand. However, it does not follow that all the particles should be large. Generally, a well-graded aggregate produces a denser and more workable concrete than an aggregate whose particles are uniform in size, a sufficient quantity of fine grains being necessary to fill the voids or spaces between the larger pieces. The shape of aggregate particles, especially of coarse aggregate, has some effect on t the density and workability of concrete. Flat particles pack loosely and hence are less desirable than those of somewhat cubical shape. Also, round particles compact more firmly and more readily than do angular particles.

24. Effects of Impurities. ___ The principal impurities in aggregates are silt, clay loam, organic matter, shale, coal, mica, and alkali. The term silt is used to designate the fine earthy material that a river carries in suspension for long distances and then deposits on its shores or bed. Silt may contain a variety of minerals depending on the nature of the land through which the river passes. The presence of a small percentage of silt, clay, or loam in a loose finely-divided condition in the aggregate is not usually harmful to concrete; on the contrary the fine materials, or fines, are advantageous in filling the spaces between larger particles. However, material in the form of a coatin on the particles of aggregate prevents the adhesion of the cement to the aggregate and weakend the concrete. A coating of vegetable or other organic matter on sand grains appears not only to prevent the cement from adhering but also to affect it chemically and to delay the setting process. The other impurities in aggregate are objectionable mainly because they are likely to disintergrate and thus cause disintergration of the concrete.

25. Test for Organic Imputities in Sand. ___ The presence of injurious amounts of organic matter in sand is determined approximately by the following test: A 12-ounce graduated prescription bottle is filled to the 4½- ounce mark with the sand to be tested, and a 3-percent. solution of sodium hydroxide (caustic soda) is added until the volume of the sand and ~~sontion~~ solution after shaking, amounts to 7 ounces. The mixture is then shaken thouroghly and left to stand for 24 hours. At the end of this period, the color of the clear liquid above the sand is observed. If the clear liquid is colorless, or has a light yellow color, the sand may be considered satisfactory as far as organic impurities are concerned. But if a dark-colored solution, ranging from dark red to black, ~~is~~ is obtained, the sand should be rejected, or used only after it has been put to the usual mortar-strength tests and found to give satisfactory results. A 3-per cent. solution of sodium hydroxide, made by dissolving 1 ounce in enough water to make 32 fluid ounces, is sufficient to test five or six samples.

26. Resistance to Wear & Weather. __ Almost all commonly used rocks offer sufficient resistance to wear and weather to warrant their employment in concrete. Certain kinds of shale, however, crumble when exposed to the weather, and rock containing fragments of shale must therefore always be viewed with suspicion. For special purposes such as pavements, special wear-resisting aggregates are often required. However, since no suitable field tests for durability have been devised only aggregates that have been used successfully under similar conditions should be employed.

27. Kinds of Concrete and Mortar. __ Concrete may be classified as portland cement concrete, natural-cement concrete, alumina-cement concrete, bituminous concrete, etc., according to the character of the cementing material used in it. However, as portland cement is used so much more in concrete than other cements the term concrete is commonly used to denote portland-cement concrete, and this custom is followed here. Depending on the kind of cement used in it, mortar is known as portland-cement mortar or natural-cement mortar. Sometimes, a part of the cement in mortar is replaced by lime, and the mortar is then called lime-cement mortar. When lime is the only cementing material in the mortar, it is known as lime-mortar. All four kinds of mortar are used extensively and, unless it is clear from the circumstances which kind is meant, great confusion is liable to arise from failure to distinguish between them.

28. Proportioning of Concrete.__ Since sand and stone are cheaper than cement, it is desirable from an economic point of view to use as much sand and stone as possible in concrete in order to make the more costly cement go further. On the other hand, the strength and durability of concrete generally decrease when the amount of cement is decreased. Also, the proportions of the ingredients must be s such that the fresh mixture will be sufficiently plastic and workable for the conditions under which it is to be placed in the forms. Therefore, it is necessary to limit the amounts of sand and stone used with a given quantity of cement paste. The limits vary with the nature of these materials and with the r requirements of the work for which the concrete is to be used. The selection of the proper relative quantities of cement, sand, and stone is call proportioning of the concrete. The main problem in proportioning concrete or mortar is to obtain the most economical mixture of satisfactory quality with the available materials.

29. Durability of Concrete.__Since concrete is made of durable materials, it will itself be durable if manufactured so as to resist attacks of disintergrating agencies. The chief of these is water. If water is allowed to enter the concrete intermittently, it tends to cause leaching out of certain desirable materials, and rusting of the reinforcing bars that may be in the concrete. Spalling of the masonry near the surface due to expansion of water while freezing is another injurious effect of that element. The solution of the problem of producing durable concrete, therefore, consists essentially in making the concrete impermeable or waterproof whenever it is to be subjected to severe exposure. Since the aggregates are impermeable, it is evident that any passage of water through the concrete must be through the hardened water-cement paste or through pores in the concrete created by improper proportioning. Waterproof concrete cantherefore be made by employing a paste that is itself impermeable, by using enough of the paste to fill the spaces between sand grains, and by having enough of the mortar to fill properly the spaces in the coarse aggregate. A relatively thick paste containing not more than $6\frac{1}{2}$ gallons of water per sack of cement is sonsidered fairly impermeable.

30. <u>Strength.</u> Concrete is ordinarily used to resist loads in compression, so that its compressive strength is taken as the measure of quality. In reinforced work, however, its power of bonding or adhering to the reinforcing bars is also important. In pavements and heavy-duty floors, resistance to wear is a factor although concrete wears but little under rubber-tired traffic. Concrete is not usually expected to resist the tensile stresses due to bending in beams, steel reinforcing bars being provided for that purpose in the parts of the beam where such stresses exist. However, the concrete in beams is expected to resist part or all of the diagonal tension, which is a form of tension produced by the shearing forces in the beam. Sometimes concrete is also expected to resist some tension due to bending, as in a pavement slab without steel reinforcement where tensile stresses may exist in parts of the slab due to the bending that takes place when the foundation soil yields or is washed away. Fortunately the bond, wear resistance, shearing and tensile strength, and water-tightness of concrete are found to be affected by the same factors that influence its compressive strength, so that it is customary to design and test concrete on a basis of the compressive strength at the age of 28 days corresponding to the quality desired.

31. <u>Workability.</u> An excellent conception of workable concrete is "an aggregate mass floated in the cement paste." In order to explain more fully the significance of this definition, it is perhaps easier to specify what a workable mix is not, than to say what it is. Thus, if the concrete is not harsh, that is, not difficult to place and finish, if it does not separate into layers of coarse aggregate and mortar, and if it can be puddled readily into the corners of the forms without leaving empty spaces or honeycomb, it is said to be workable. In other words, workable concrete should be free from harshness, segregation of the coarse aggregate, and honeycomb. The workability of a concrete mixture is commonly indicated by its consistency. Harshness may be caused by a deficiency of sand in the mix, that is, by an undersanded mix; by lack of fines in the sand; by the use of less mixing water than is required; or by an excessively lean mix due to the use of too little cement in proportion to the total amount of aggregate. Segregation of the coarse aggregate is almost invariably caused by the use of too much mixing water. The effect of excess water is aggravated by undersanding the mix and by allowing the plastic concrete to flow to place in the forms. Honeycomb may be cause d by undersanding or by the use of an extremely dry mix that is not compact by tamping. Excess workability may be obtained by employing too much sand or oversanding the mix, by using a very rich mixture, or by adding excess water. Oversanding reduces the strength of the concrete, and unnecessary richness increases the cost of the mixture; excess water results in a great decrease of strength and its use is to be condemmed. Extremely rich mixtures that are too wet also tend to segregate. A workable mix may appear undersanded, but it can be easily finished with a trowel to present a smooth surface. In the undersanded mix there is not sufficient mortar to fill the spaces in the coarse aggregate, and the concrete will show hineycomb in the forms. The oversanded mix is very plastic.

32. <u>General Features.</u> The fundamental requirement of proportioning concrete mixtures are: (1) Each particle of fine aggregate must be coated with a film of cement paste and each particle of coarse aggregate must be coated with mortar; (2) all the voids or spaces between the individual grains must be filled. (3) the cement paste itself must be of the proper quality. Economy dictates that a given quantity of paste be used to bind together a maximum amount of aggregate.

33. Economy. The relation between strength and economy in proportioning concrete mixtures is important. It is possible to change proportions in three ways: (1) The mix may be made richer or leaner by using more or less cement; (2) it may be made wetter or dryer by using more or less water; or (3) the grading of aggregate may be made finer or coarser by using more or less sand in proportion to coarse aggregate. Changes in the mix affect the strength or economy of the concrete, as follows: Richer mixtures, drier consistencies, or coarser gradings produce higher strengths when other factors are kept constant because less mixing water per sack of cement is required. Leaner mixtures, drier consistencies, and coarser gradings produce more economical concrete of a given strength, because less cement in proportion to aggregate is necessary. Hence, economy is obtained in practice by using well-graded aggregates and the driest concrete mixtures that can be easily worked.

34. Coating Aggregate. Since the grains of sand and coarse aggregate remain entirely inert until coated with a film of cement paste, it is most important that there be at least sufficient cement paste to coat each grain of sand in the mortar, and sufficient mortar to coat each particle of coarse aggregate. Otherwise, the adhesion between the particles will be limited.

35. Filling Spaces. A mixture so proportioned that each particle of aggregate is coated with cement paste will be strong; but if the voids, or spaces be tween the particles, are not filled, it will not be dense, and the concrete will contain many pores and ducts through which water may enter the masonry. The ideal way of filling these spaces is so to proportion the mix that all the interstices between the larger pieces of aggregate are filled with smaller pieces, that the spaces between the smallest pieces of all are filled with cement paste, and that the cement paste itself is composed largely of solid matter, the water being combined chemically with the cement. Complete elimination of the voids is a condition rarely, if ever, attained in practice, but the more nearly this ideal is approached in any given case the more satisfactory the work will be. The use of sands that are too coarse for the mixture results in harsh mixes, difficulty in finishing, and porous concrete containing minute voids. A well-graded sand required less cement paste, and is more workable for a given amount of paste. A properly sanded concrete not only is more workable and plastic while fresh, but also when hardened contains less pore space and no honeycomb.

36. Quality of Paste. Minute voids in the concrete may be caused by excess mixing water in the cement paste. Less than half the water ordinarly used in mixing actually enters into combination with the cement to form hardened concrete. The excess remains scattered throughout the mass in the form of very small drops which in time evaporate or seep away, leaving a corresponding volume of pores. The amount of water used im mixing therefore affects not only the strength but also the density and permeability of the masonry; hence, water over the actual needs of the cement should be kept at a minimum.

37. Arbitrary Proportions. A common method of proportioning concrete mixtures is to specify the number of cubic feet of sand and coarse aggregate to be mixed with each sack of cement. When this practice is adopted, it is customary to use half as much sand as coarse aggregate. For ordinary purposes, the concrete mix consists of 1 bag of cement, which is assumed to have a volume of 1 cubic foot; 2 cubic feet of sand, measured damp and loose as it comes from the stock pile; and 4 cubic feet of coarse aggregate, also measured damp and loose. This is called a 1:2:4 mix. Mixtures in the proportion 1:1:2:, 1:1½:3, 1:2½: 5, and 1:3:6 are also used under certain conditions. For many years it has been assumed that the 28 day compressive strengths corresponding to these mixes would be as shown in Table 3, but the cements now used give much higher strengths.

38. Objections to Arbitrary Proportions. __Concrete mixtures designed on the basis of arbitrary proportions are defective for several important reasons. The method is obviously faulty because no account is taken of the water content. For example, a 1:2:4 mix may have a strength anywhere between 1,000 and 3,000 pounds per square inch, depending on the amount of water used in the mix. Again, the voids as measured in the loose aggregate do not indicate the amount of space to be filled in the concrete, as the pieces of coarse aggregate in concrete are forced apart by the sand grains and are therefore more widely separated; it is well known that a cubic yard of concrete is produced from less than a cubic yard of coarse aggregate. Furthermore, sand as measured damp and loose in the field is subject to bulking or fluffing apart of the particles, and the volume of bulked sand is not always sufficient to fill the voids, because the sand loses its bulking property when mixed in concrete. Hence, the volume of sand in the average mix should be more nearly two-thirds than one-half of the volume of coarse aggregate. The exact amount should be determined by trial.

39. Quantity of Mixing Water. __According to the water-cement-ratio law, the maximum quantity of mixing water per sack of cement is fixed by the specified strength of the concrete. The best known relation giving definite values for the water-cement ratio corresponding to the compressive strength of concrete at the age of 28 days was developed by Professor Duff A. ~~Adams~~ Abrams. This relation, expressed by Fig. 14, was derived from several thousand laboratory tests including a wide range of mixes, consistencies, and gradings. It is seen that the strength is decreased as the water per sack of cement is increased. For example, concrete whose compressive strength is 3,000 pounds per square inch may be expected to result from the use of not more than 6 gallons of mixing water per sack of cement, and 2,000 pound concrete should result if $7\frac{1}{2}$ gallons per sack are used.

40. Quality of Water! __The water used in mixing concrete should be clean, fresh and free from dirt or vegetable matter. Water containing even small quantities of acid may seriously injure the concrete. The presence of oil will result in slow setting and decreased strength. Salt is sometimes added to the water in mixing concrete for winter work, because salt lowers the freezing point of water and thereby delays the freeing of concrete. Salt so used is objectionable because it delays the hardening and decreased the strength and chemical compounds are formed that crystallize on the surface of the masonry as a whitish deposit called efforescence, which is unsightly.

41. Relation of Time to Water-Cement Ratio. __It has been pointed out that the quantity of mixing water is a function of the strength of concrete, but it was assumed that all of the mixing water is retained in the concrete until the cement sets, usually in about 3 to 5 hours. If, however, some of the excess~~ii~~ mixing water is withdrawn before the cement sets and the concrete is allowed to settle and compact, the effect is practically the same as if the water had been omitted in the first place; in other words, the water-cement ratio at the time of set governs the quality of the concrete. Loss of water after that time does not compact the mass but merely leaves small air spaces in the hardened concrete.

42. Design of Mix. __The design of a concrete mixture consists of the selection of the water-cement ratio~~s~~ that corresponds to the desired strength, and then finding the most suitable combination of aggregate whhich will give the desired workability.

43. Job Conditions. The strengths of different concrete mixtures having the same water-cement ratio might vary, depending on the character of the materials; the methods of mixing, placing, and curing the concrete; the temperature; etc. Usually the job strength will be greater than that taken from the Abrams curve, and it is customary to use this curve as a basis for design of mixtures. After the job is started, tests may be made to determine the effect of job conditions by finding out the strength obtained from a particular water-cement ratio. The point corresponding to the observed strength and the given water-cement ratio can be plotted on a diagram and a job curve may be drawn which will represent accurately the strength to be expected from any water-cement ratio used on that job.

44. Moisture in Aggregates. Since most aggregates contain considerable amounts of moisture when delivered to the job, the volume of water to be added to a batch of concrete must be less by an equal amount to produce the desired water-cement ratio. For instance, suppose that the amount of water in a cubic foot of sand is $\frac{1}{2}$ gallon and that in a cubic foot of coarse aggregate is $\frac{1}{4}$ gallon. Then, in a 1:$2\frac{1}{2}$: 4 field mix based on a water-cement ratio of $7\frac{1}{2}$ gallons, the amount of moisture per sack of cement in the sand is $2\frac{1}{2}$x$\frac{1}{2}$ equals $1\frac{1}{4}$ gallons, and in the coarse aggregate is 4x $\frac{1}{4}$ equals 1 gallon. Hence, the amount of water to be added to the mixture per sack of cement is $7\frac{1}{2}$-$1\frac{1}{4}$ - 1 equals $5\frac{1}{4}$ gallons. A number of methods are employed to determine the moisture content of aggregates, the simplest of which is to dry out a small sample by air drying or heating and to observe the loss of weight of the sample. An ordinary postal scale is accurate enough for this determination if carefully handled. On the job, the moisture varies somewhat, and, in order to maintain a uniform water-cement ratio, the amounts of water added at the mixer need to be increased or reduced accordingly; however, these changes are not large, nor do they occur rapidly. The coarser the aggregate the less water it will carry.

45. Water absorbed by Aggregates. Aggregates absorb water, some more than others. Approximate amounts of absorption by weight are: 1 per cent. of average sand, pebbles, or crushed limestone; $\frac{1}{2}$ per cent. of trap rock or granite; 3 per cent. of average blast furnace slag. Light and porous aggregates absorb considerably more than these amounts, and should be tested by soaking a dry sample in water for 30 minutes, wiping the surface water from the particles, and observing the gain in weight. In practice, absorption is generally neglected, as it is small in amount and the quality of the concrete is improved by its effect. Aggregates do not usually absorb much water from the cement paste, but when exposed to the drying effect of the sun and the wind some aggregates may absorb large quantities. Evaporation from the concrete mass is also increased by sun and wind. To prevent shrinkage cracks in the fresh concrete from excessive loss of water, the aggregate may be wetted down before the concrete is mixed; in this way a uniformly moist aggregate is obtained, and it is easier to maintain a constant strength and consistency.

46. Desirable Proportions of Fine and Coarse Aggregates. Owing to the wide variety of grading of aggregates used in concrete, no fixed rule of proportioning can be applied to all cases. For each job, and for each set of aggregates available, there is an ideal combination which should be determined according to one of the methods of proportioning that have been proposed by various engineers. The simplest method is by diredt trial of the materials in an actual mix. Within the range of possible combinations there are three classifications of mix: (1) grossly oversanded, (2) workable, and (3) harsh or undersanded. For a grossly oversanded mix, excessive water is required, which reduces the strength of the mixture, and the concrete is likely to be porous. Decreasing the proportion of sand by replacing sand with coarse aggregate increases the strength, because less mixing water is required to lubricate the larger particles. Beyond a certain point, however, the sand is insufficient to fill the spaces in the coarse aggregate, and harshness results; since the harsh grading can only be made workable by flooding with water, the strength is reduced. An increase in the proportion of sand to coarse aggregate in a workable mix reduces the strength of the concrete, but such an increase in a harsh mix increases the strength. Lack of understanding of this basic fact if often responsible for employment of harsh mixes in concrete work. There is an erroneous notion among some concrete men that sand hurts concrete, whereas sand is less harmful than the excess water which is required for harsh mixes. Of course, grossly oversanded mixes are to be avoided, as ither the strength or yield is reduced. With a fixed water-cement ratio and a given coarse aggregate, less of a fine sand than of a coarse sand will be required to obtain a specified consistency. More of a given sand will be required (1) when the maximum size of coarse aggregate is reduced; (2) when the particles of coarse aggregate are nearly all of one size; or (3) when the coarse aggregate consists of rough or angular particles rather than smooth, rounded pebbles. Hence, under a rigid specification for a mix known to be undersanded, the use of fine sand or a large size of coarse aggregate will relieve harshness.

47. Bulking of Aggregates. When moisture is added to dry sand, a film of water is formed on the surfaces of the particles, fluffing them apart. On account of the increase in volume due to fluffing and lack of compaction of the particles, which is known as bulking, the volume of damp loose sand used in a concrete mix may be only the equivalent of a much smaller volume of dry compacted sand. The amount of bulking depends on the percentage of moisture, the method of measurement, and the sizes of the sand grains. An amount of moisture equal to 1 per cent. of a given sand will cause the sand to bulk several per cent. The bulking increases rapidly until the amount of moisture is about 6 per cent. by weight, when the bulking may be as much as 20 or 25 per cent. Further additions of water tend to flood or pack the sand , decreasing the amount of bulking. When some 20 or thirty per cent. of water is added, the sand is completely flooded or inundated, and the volyme of sand is approximately the same as when the sand is measured dry. Bulking of a given sand with a given moisture content is less when measuring container is large, because the sand is compacted somewhat under pressure. Even when the sand is compacted, however, the bulking is considerable. The finer the sand, the more it will bulk for a given moisture content and method of measurement. In the case of coarse aggregate, the effect of moisture in ~~the~~ causing bulking is slight. Most of the so-called bulking in coarse aggregate which is usually not more than about 6 per cent is due to loose measurement and not to fluffing apart of the particles of the material.

48. <u>Methods of Designing Mix.</u> When mixtures are designed according to the water-cement ratio principle, the quantity of mixing water per sack of cement is fixed by the required strength of the concrete, and it remains to find an economical combination of aggregates that will produce a workable mix with the relative volumes of cement and water. Concrete mixtures may be proportioned by trial, or on the basis of calculations made by any of several proposed methods. The trial method is usually preferred because of its simplicity and directness. According to this system of proportioning concrete, actual mixtures are made by using the proper water-cement paste and adding aggregates to obtain the best yield and workability. The trial mixes can be made either in the laboratory before the job is started or in the mixer on the job.

49. <u>Method of Mixing.</u> Concrete is usually mixed in batches; that is, a batch composed of measured quantities of cement, water, and aggregates is assembled, mixed, and removed to the forms. A batch usually contains a whole number of full bags of cement, and is referred to as a one bag batch, a two bag batch, and so on, as the case may be.; the only fractions of bags that should be used are half bags, unless the cement is weighed. There are two methods of mixing concrete; namely, machine mixing and hand mixing. Practically all concrete, even for small jobs, is mixed by machine.

Machine mixers are of two classes, namely, batch mixers and continuous mixers. In the batch mixers, measured quantities of materials for a batch of concrete are fed into a power-driven revolving steel drum in which there are blades or buckets that handle the ingredients so as to mix them thoroughly. The mixing of each batch should continue from 1 to $1\frac{1}{2}$ minutes after all the materials are in the mixer and the perpheral speed of the blades should be about 200 feet per minute, ~~,~~ or the drum should revolve ~~as~~ at a speed of 15 to 20 revolutions per minute. The batch is discharged by tilting the drum or by swinging a chute into a position where it will catch the plastic concrete and carry it out of the drum. Each batch is handled as a unit and no fresh material is added until all the mixed material has been removed from the drum.

In a continuous mixer raw materials are stored in a series of hoppers placed over one end of a semicircular trough in which revolves a shaft that has blades or shovels attached to it. The motive power is generally a gasoline engine or an electric motor. Dry materials are fed automatically from the hoppers into the trough, and are mixed and carried along by the blades to the discharged end, water bieng added in transit. The distinctive feature of this type of mixer is that concrete is discharged continuously from one end of the trough. Batch mixers are used almost exclusively in engineering work, and the use of continuous mixers is confined to mixing mortar for brick and stone masonry and to mixing concrete for concrete products and small foundations. One objection to the continuous mixer is that the quality of the concrete is not uniform because variation in the moisture content of the aggregate or irregularity in the flow of cement from the hoppers is likely to prevent uniform proportioning. The other important objection is that the time of mixing is not under such control as in the batch mixers.

50. <u>Time Required for Mixing.</u> Concrete should be mixed for a time sufficient to insure uniform distribution of particles and paste throughout the mass, eliminating dead spots, and to coat each particle with the paste. The strength of concrete increases with additional time of mixing, the increase being considerable during the first minute and less during each successive minute. Longer mixing also increases the plasticity of a batch of concrete and there is evidence to indicate that the water-tightness likewise is benefited. The exact point at which additional mixing ceases to be worth while depends on the class of work, size of mixer, type of mixer, and other conditions of the job. For instance, a large batch requires longer mixing than a smaller batch. A good rule is to continue mixing for one full minute after all materials are in the mixer before anything is withdrawn.

51. Measuring Materials. __On Many jobs, the aggregates are simply loaded into wheelbarrows and dumped into the mixer, each barrow being assumed to hold a certain volume of material. However, owing to the important effects of bulking and poor grading of aggregates, care should be taken, even when such a rough method is used, to load the wheelbarrows with nearly constant quantities. More uniform methods of measuring aggregates have now been developed. Batchers that measure proportions by volume give good results if bulking is compensated for properly. Nevertheless, since measurements by weightgive absolutely uniform proportions and avoid the necessity of allowing for bulking, weight batchers are coming into more general use. Even when the aggregates are weighed, however, it is necessary to take into account changes in the moisture content of the aggregate so as to provide the proper amount of mixing water. Many concrete mixers are equipped with water-measuring tanks that can be set to give a constant volume of water for each batch ofconcrete. These tanks can be accurately adjusted, and the setting locked by the inspector. Some of them have been improved to prevent leakage of water into the mixer while the concrete is being discharged, and to insure constant amounts of water even when the mixer is on sloping ground. Accurate measurement of both sand and water can be accomplished by the use of a device called an inundator, in which the bulking of the sand is destroyed by measuring it in a saturated condition.

52. Transporting Concrete. __Concrete is hauled from the mixer to the forms in carts or trucks, or it is raised on a hoisting tower and made to flow into the forms through chutes or spouts. Wahtever method of transportation is employed, precautions should be taken to prevent segregation of the coarse aggregate from the mortar. Unjuly wet mixes cannot be transported far without settling of the larger particles to the bottom, leaving the fines and water at the surface. On the other hand, sufficiently plastic mixes can be hauled without segregation, and cna in many cases be chuted with good results. Concrete mixed at a central plant and transported for a long distance to the forms requires a rather dry consistency to prevent segragation during hauling. Concrete transported in this way should not be placed directly in the forms but should be dumped on a platform and rehandled into the work.

53. Placing Concrete. __Concrete should be deposited as nearly as possible in its final position, as flowing in the forms tends toward separation of the water and fines from the rest of the mass. Entrapped air should be permitted to escape by tamping or puddling the wet concrete in the forms. Spading the concrete next to the forms will make surface finishing easier. Accumulation of water on the surface of concrete during plading should be avoided by proper proportioning; if, however, such a layer of water is unavoidably formed, it should be drained off. When depostied in forms, the concrete should have a temperature of not more than 120 degrees F. nor less than 40 degrees, a good average temperature being 60 to 70 degrees.

54. __Surface Finish.__ Concrete surfaces are susceptible to a variety of finishes. In ordinary work, as in walls, piers, and abutments, a satisfactory surface is obtained by using smooth and tight gorms which are held rigidly in place and by spading the concrete carefully next to the forms. Where desired, a smoother finish may be given to the concrete surface by wetting it with water as soon as the forms are removed and rubbing it with a brick of coarse carborundum or of mortar. There are various tools for giving a concrete surface the appearance of stonework. A sand blast is sometimes used when the expense involved is small compared to the cost of the structure. If the forms are removed about 12 hours after the concrete has been placed, the surface mortar can be brushed off and the broken stone exposed by means of a steel or stiff rattan brush. When the concrete surface is finished by means of a steel trowel, care should be taken to avoid overtroweling, as it draws cement and fines to the surface and causes surface cracks or checking. Ordinarily a wooden float will give best results. In two-course work, such as floors, stucco, etc., the finish coat should not be richer nor made with finer sand than the mortar of the concrete underneath, as the richer or finer mixes have a higher rate of expansion and contraction, and cracks are likely to result.

55. __Curing.__ The hardening of concrete is caused by a chemical reaction between water and the cement particles, which is known as hydration of the cement. Therefore, although an excess of mixing water weakens the cement paste in concrete, it is desirable to prevent concrete from drying out too quickly. The process of keeping concrete damp and at a favorable temperature for a certain length of time to insure complete hardening is called curing the concrete. No part of the process of concrete manufacture has a better effect on its quality than curing. In a typical case under observation, the strength was increased 50 per cent. by keeping the concrete damp 7 days and 100 per cent by damp curing for 2 weeks. Watertightness is improved in a similar manner, as the combination of water with cement results in greater density and less pore space. Continuous damp curing is a major factor in preventing checking and dusting of floors, pavement, etc., especially if the moisture is applied soon enough to prevent the surface from drying out and shrinking before the concrete has hardened. Since concrete as mixed contains an excess of water over that required for hydration, the problem of curing becomes that of keeping the entrained water inside the concrete. If the surface could be effectually sealed, perfect curing would result. Present methods of sealing, however, appear to lack effectiveness in preventing evaporation of water from the hardened concrete. The most reliable method of curing concrete appears to be the application of water to exposed surfaces by sprinkling or ponding, or by covering the surface with damp sand, earth, straw, canvas, or other suitable material. This method has the advantage of giving excellent curing conditions at the surface, the most important place. Exposed surfaces should be protected from drying out for at least 7 days, a longer period being advisable, if practicable. Vertical surfaces may be protected by leaving forms on as long as possible, or by hangings of canvas or burlap kept sprinkled.

56. High-Early-Strength Concretes. ___Quick-hardening concrete is used in special construction, such as pavement repairs, high-speed building construction, and cold weather work. The chief high-early-strength concretes are produced (1) by means of high-alumina cement or special high-grade portland cement mixes, (2) by the use of special mixes of ordinary portland cement, and (3) by the addition of accelerating admixtures. High-early-strength concrete may be made with ordinary portland cement by applying the following directions: (1) Use a very rich mix, sontaining about 50 per cent more cement than is usual, and a dry consistency; a low water cement ratio is then possible. (2) Mix the concrete from 3 to 5 minutes. (3) Keep the temperature of the concrete as high as practicable. (4) Tamp the concrete or compact it by other means. It is also important that a temperature of not less than 70 degrees F. be maintained during the curing period. The accelerating admixture that is generally employed is calcium chloride. It should be tried out with the particular brand of portland cement used in the work, as it does not give favorable reaction with all cements.

57. Cold Weather Work. ___The rate of hardening of concrete is increased at temperatures higher than normal, whereas for temperatures lower than 40 degrees Fahrenheit the process of combination of water and cement practically ceases. In freezing weather it is important to maintain the temperature of the concrete above 50 degrees until it has hardened sufficiently to resist freezing. Common practice fixes the time limit at the age when the concrete develops one fourth of its 28 day strength; this stage of hardening is ordinarily reached in 5 days. Protection is usually accomplished by canvas covers, alalmanders, or steam heat inside the structure, or similar means, care being taken to keep the air from drying out. Manure should not be used because it contains acids that injure the cement. Aggregates and mixing water may be heated before bing used in the mixture provided the heat is sufficient to spall the aggregates nor cause caking or flash set of the cement. A safe maximum temperature for fresh concfete at the mixer is 140 degeees F. To insure a certain temperature of the concrete when deposited in the forms, the temperature at the mixer should be about 20 degrees higher. Accelerators such as calcium chloride are sometimes used in cold weather work with good results. Their function is to hasten the hardening process and reduce the required time for heating and protecting the concrete. The curing period during which protection is necessary is also materially shortened when special concretes that develpp high early strength are employed.

58. Joining New Concrete with Old. ___New and old concrete can be joined only with great difficulty, and ths strength of such a connection is always uncertain. The joining is best done by chipping and cutting away the old surface, thoroughly cleaning it of all dust, dirt, and loose particles, saturating it with water, painting it with a cement grout paint mixed to the consistency of thick cream, and then, while this coating is fresh, immediately placing the new concrete. As cement begins to harden within a very short time after combining with water, the grout paint should be applied only a short distance in davance of the work of depositing. The cleaning can be done very thoroughly by means of wire brooms and water under pressure.

59. <u>Depositing Concrete Under Water.</u> Three different methods have been successfully used for depositing concrete under water; namely, (1) cloth bags, (2) buckets, and (3) a tremie, or spout. The buckets are open at the top, and are provided with doors at the bottom which open downwards. The bucket should be completely filled and lowered slowly. It should not be discharged until it rests on the surface to be concreted, and should be withdrawn slowly until clear of the concrete. In some cases large bags of loose weave have been filled with concrete and lowered to position in the water; the bags were left in place with expectation that sufficient of the cement would seep through the loosely woven material to cement the bags together. In other cases, smaller bags of closer weave with an opening in the bottom have been used. The tremie is a water-tight tube sufficiently large to permit the free flow on concrete through it. There is usually a hopper at its upper end to better receive the concrete. Its lower end is temporarily closed and it is lowered into position, resting on the surface to be concreted. Newly mixed concrete is then fed into the hopper above the water until the tremie is full of concrete and the concrete flows out at the bottom. After a while the flow will cease because the concrete piles up around the bottom of the tremie, choking off the stream. The apparatus is then lifted a few inches and when the flow starts anew the tremie is slowly swung over the area to be concreted, the hopper being always kept full. If the tube is raised too high, the concrete escapes all at once and the tremie must then be with-drawn and refilled. If the concrete is too wet, the charge in the tremie is liable to run out, while if too dry, the concrete may block the passage through the tube. In placing concrete under water, extreme care must be used to prevent the water from washing the cement away from the mixture. To avoid this, the concrete should not be permitted to fall through the water, and no current of water should strike the concrete before it hardens. It is therefore necessary to surround the space to be concreted with a water-tight form. Concrete for use under water should contain more cement than that used for work on dry land and the amount of fine and coarse aggregate combined should never exceed six parts to one of portland cement. Hand mixing should not be permitted. The concrete should be deposited continuously and with sufficient rapidity to insure bonding of the successive layers. The top surface should be kept nearly level. While being deposited, the concrete should be disturbesd as little as possible to prevent the formation of laitance, which is a chalky deposit of low strength composed of extremely fine particles that separate from the freshly laid concrete and collect on the top surface.

60. <u>Waterproofing Concrete.</u> All concretes absorb water to a greater or less degree. Therefore, they not only permit dampness to penetrate a building, but also tend to permit destruction by frost. Portland-cement concrete may best be made almost impermeable by using aggregates that have been carefully graded and by adding hydrated lime. If further protection is desired, a common method is to apply a wash of waterproofing to the finished surface, which fills the voids in the mortar and also forms a coating. For this purpose paraffin can be used; solutions of soap and alum applied alternately combine to form insoluble acids and also give good results. These coatings are easily and cheaply applied but the objections to their use are that ehey are liable to crack when the masonry cracks and they are liable to separate from the masonry and peel off. A more effective method is to coat the hardened concrete with an esastic membrane such as bitumen or coal-tar pitch reinforced with felt or fabric. These membranes are expensive and, as they are susceptible to injury from the outside, they are usually protected by a covering of brick or concrete which increases the cost.

61. <u>Volume Changes In Hardening Concrete.</u> Concrete contracts upon initial drying out in air, to the extent of about .05 per cent. or 6 inch in 100 feet. The amount of this shrinkage does not appear to be affected by the water-cement ratio or by the extent of curing, but it is increased by a greater cement content or by an excess of fine dust in the aggregate. If concrete is rewetted after drying out, it expands to the extent of about 04 per cent., but it contracts about the same amount upon subsequent drying out. On the other hand, if concrete is cured damp for a period of several weeks from the time it is placed, it expands about ¾ inch in 100 feet.

62. <u>Expansion and Contraction of Concrete.</u> Nearly all materials expand slightly as they become heated and contract while cooling, and concrete follows this law. The generally accepted value of the coefficient of expansion of average concrete due to temperature is .0000055 for 1 degree Fahrenheit; this amounts to a change in length of .0066 inch in 100 feet for each degree of change in temperature.

63. <u>Colored Concrete.</u> The natural color of portland cement concrete may be varied to meet architectural requirements by the additon of suitable tinting materials. Because of the chemical reaction that takes place between cement and organic pigments, nothing but mineral pigments should be used to color concrete. Too large a proportion of pigment tends to impair the strength of the cement, and, in general, it is found that an amount of pigment exceeding 5 per cent. of the weight of the cement should not be used. Coloring matter should always be thoroughly mixed with the dry cement before water is added. Weighing of cement as well as coloring matter is preferable to measuring by volume, since weighing is more exact, and ingredients must always be exactly proportioned to prevent variations in the tint.

64. <u>Proportions of Cement Mortar.</u> Portland cement mortars are made in proportions varying from 1:1; to 1: 6 . The richer mixtures are used for facing of concrete blocks and other ornamental concrete products, for waterproofing surfaces, for wearing and finishing coats on floors and pavements, etc., the 1:2 mixture being usually employed for such purposes. The leaner mixtures are used for rough work, filling, backing, etc., but should never be employed where either much strength or much density is desired. The number of parts of sand in natural cement mortar is commonly made one less than in portland cement mortar used for the same purpose, although a decrease of about 2 parts of sand is necessary to produce the same strength. For example, where a 1: 3 portland cement mortar would be used, a 1: 2 natural cement mortar is substituted; however, the strength of a 1: 2 natural cement mortar is only equivalent to that of a 1: 4 portland cement mortar. Cement mortar mixtures are usually provided by arbitrary proportions, sufficient water being added to give a desired workability or consistency. However, when mortar of a certain strength is required it is best to proportion it by the trial method in the same manner as for a concrete mixture. For general purposes, the mortar should be of a plastic consistency -- firm enough to stand at a considerable angle, yet soft enough to work easily. The consistency of the mortar should vary with the materials used and with the conditions to be met.

65.
Mixing. A complete and uniform mixture of the separate ingredients of cement mortar is best obtained by means of mechanical contrivances; but, since mechanical mixers are rather expensive to install and operate, it is only where large quantities of material can be used in a short time that such appliances can be employed to advantage. Mortar that is to be mixed by hand is prepared on a platform or in a mortar box. The sand is first measured by means of a bottomless barrel, or, better, by means of a low, square, bottomless box with handles on the sides and of such a size that it will give the correct quantity of sand. After the box is filled, the sand is struck off level, the box lifted up, and the sand spread in a low, flat pile. The required quantity of cement is then placed on the sand and spread evenly over it. The pile is then turned over and mixed with shovels, the materials being worked over not less than four times. After this operation, the dry mixture is formed into a ring, or crater, and the water intended to be used is poured into the center. The material from the sides of the basin is then shoveled into the center until the water is entirely absorbed, after which the pile is worked again with shovels and hoes until the mixture is uniform and in a plastic condition. In mixing, the mortar should be completely turned over not less than four times dry and from four to six times after the water has been added. Another method of mixing, where a mortar box is used, is to gather the mixed dry materials at one end of the box and pour in the water at the other end, drawing the mixture into the water with a hoe in a little at a time, and hoeing until plastic consistency is obtained.

66. Strength of Cement Mortar. The structural value of a mortar depends on its resistance to tensile, compressive, tranverse, and shearing stresses, and also on its adhesion to inert surfaces, its resistance to impact and abrasion, etc. In masonry construction, although mortar is generally subjected only to compressive stress, it is also at times called on to withstand tensile, transverse, and shearing stresses. There is no definitely fixed ratio between the strengths of mortar subjected to these different stresses, but there is a close relation between them; hence, it may be assumed that if a mortar shows either abnormally high or low strength in any one test, it will develop proportionally high or low values when tested under other stresses. In practice, therefore, the tensile or compressive strength of mortar is commonly determined and its resistance to other forms of stress is estimated from these results. The tensile or compressive strength of mortar varies with the character and proportions of its ingredients, with its consistency and age, and with many other factors. A mortar that is to be used in important construction should show tensile or compressive strengths not less than those of a mortar made of the same cement mixed with the same proportion of standard Ottawa sand and possessing the same consistency.

67. Useful Data on Cement Mortar. The following brief sentences summarize the important points to be remembered concerning the cement mortar.

1. The stength of a mortar depends primarly on the percentage of cement in the mixture, and on the volume of mixing water per sack of cement.

2. The most economical moratr for a specified strength is obtained by using a well graded sand and the driest mixture that will be workable.

3. The best sand is, in general, that which will produce the smallest volume of martar when mixed with the cement in the required proportions.

4. Sharpness of sand grains is of slight importance.

5. Coarse sand produces stronger mortar than fine sand.

6. Fine sand requires more water than coarse sand to produce a mortar

is less dense.

7. Mixtures of fine sand and coarse, or of sand and screenings, often produce better mortar than either material alone.

8. Imputities in sand, such as vegetable loam, even in a minute quantities, may injure the strength of the mortar.

9. The average weight of portland cement mortar in pproportions 1: 2½ is 135 pounds per cubic foot.

68. Use of Lime Mortar. __Lime mortar is employed chiefly for brickwork of the second class such as is commonly used in the walls of smaller buildings, and its ~~ffff~~ use is continually decreasing as that of cement mortar is increasing. It is absolutely unsuitable for any important construction, because it has little strength and is porous. It cannot be used in damp or wet situations, nor should it be laid in cold weather; the mortar is materially weakened by alternate freezing and thawing before it has set. Moreover, since it hardens by the action of dry air, only the exterior of lime mortar ever becomes fully hardened. The mixtures employed vary from 1: 2½ to 1: 5. Building laws in many municipalities require the use of a 1: 3 mixture, and for most materials this proportion will be found satisfactory.

69. Mixing Lime Mortar. __In mixing lime mortar, a bed of sand is made in a mortar box and the lime is distributed as evenly as possible over it, both the lime and the sand being first measured according to the specified proportions. The lime is then slaked by pouring on water, after which it should be cofered with a layer of sand, or preferably a tarpaulin, to retain the vapor given off while the lime is undergoing the chemical reaction of slaking. Additional sand is then used, if necessary until the mortar attains the propor proportions. Care should be taken to add just the proper quantity of water to slake the lime completely to a paste. If too much water is used, the mortar will never attain its proper strength, while if too little is used at first, and more is added during the process of slaking, the lime will have a tendency to chill, thereby injuring its setting and hardening properties. Rather than make up small batches it is considered better practice to make lime mortar in large quantities and to keep it standing in bulk so that it can be used as needed.

City Engineer.

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CONCRETE

1. Kinds of Cementing Materials. ____ A material which by proper treatment can be made plastic and which will then gradually harden to form a solid mass is called a cementing material. Most cementing materials become plastic when water is added to them, and then harden because of a chemical process. Portland Cement, which is the cementing material used most extensively in construction, is in this class. Other materials in this class that are used in construction are natural cements, high-alumina cements, limes, plaster cements, and puzzolans, or slag, cements. Bituminous, or asphaltic, cements become plastic when heated and harden on cooling. They are used mainly as binders in road construction and in the preparation of waterproofing paint. The particles of cementing materials not only cohere to each other on hardening, but also adhere to other materials with which they are in contact and, therefore, cementing materials can be used to bind bodies together.

2. Mortar. ____ A mixture of sand and a cementing material in proper proportions and in a plastic state is called mortar. In hardening, the cementing material binds together the particles of sand and forms a solid mass. Mortar also adheres to other larger bodies between which it is placed and these bodies can, therefore, be bonded by the mortar. Thus, bricks or stones are bound together in a wall by laying mortar between them.

3. Concrete. ____ If pieces of broken stone, gravel, cinders, or slag are mixed with a mortar of sand, cement, and water, concrete is formed. When freshly mixed, concrete can be poured into molds or forms, and on hardening will take shape in the mold. Concrete is extensively used in all kinds of construction; when used in combination with steel rods, it is known as reinforced concrete.

4. Aggregates. ____ The inert material which is bound together by the cement in concrete is called aggregate. The part of the aggregate which is less than ¼ inch in size is generally called the fine aggregate and usually includes only the sand. The remainder of the aggregate is called the coarse aggregate. The maximum size of the coarse aggregate in ordinary concrete work is 3 inches.

5. Setting of Cement. ____ When water is added to cement, a paste is formed which remains plastic for a time and then, if undisturbed, begins to lose its plasticity, or to set; finally, it becomes rigid. The chemical changes that take place in the cement when water is added are not thoroughly understood, but it is known that the action of the water on the cement results in the formation of both crystalline and jelly-like products. These products adhere to each other and to surfaces in contact with them and eventually become very hard. If the materials are kept moist, the chemical reactions may continue for years and the structure may gain in strength over a long period of time. In order that cement in mortar or concrete may harden properly, it is important that the correct amount of water be used and the materials be mixed and handled in the right manner. During the early stages of the setting process, the product may be disturbed without being injured, but after the reactions have reached a certain stage, the strength of the product is seriously impaired by disturbing the particles of cement. It is very helpful in construction that the hardening process does not start until sufficient time has elapsed to permit the thorough mixing of mortar or concrete, the transportation of the mixture from the mixer to forms, and the proper placing of it in the forms.

Under certain conditions cement may have a very quick set, or so-called flash set. Such cement cannot be used for ordinary purposes because concrete made with quick-setting cement cannot be mixed and placed properly. In the setting of cement, two stages are recognized: First, the initial set, when the paste begins to harden, or to offer resistance to change of form; and, second, the final set, when the setting is complete, or when the mass cannot be appreciably distorted without rupture.

6. Reasons for Fineness Test. ____ The fineness of cement is important because it affects both the strength and the soundness of the product. The more finely a cement is ground, the more thoroughly will the cement paste cover the particles of sand, and hence the greater will be the strength of the resulting mixture. Moreover, as the fine particles are more quickly acted on by the mixing water, the crystallization is hastened. Therefore, not only the ultimate strength of the product but also the early strength is increased. Fineness of grinding affects the soundness of cement because the expansive elements contained in the coarse particles are not readily susceptible to the action of seasoning, which will hydrate and render inert the unsound material in the fine particles.

7. Definitions: ____ The strength and other properties of hardened cement paste, mortar, or concrete vary considerably with the percentage of water used in mixing, that is, with the consistency of the fresh mixture, which is a term employed to express the degree of plasticity of the mixture. In order to provide a basis for comparison, when cement is tested it is essential that the amount of water used in preparing the paste or mortar for the test should be such as to bring the plastic mixture to a standard physical condition. This condition is called normal consistency. Different cements require different per cents of water to make a specimen of normal consistency because of their varying chemical composition, degree of burning, fineness, age, etc.

8. Approximate Test. ____ An approximate and convenient method for determining normal consistency is to form the paste into a ball about 2 inches in diameter and to drop this ball on a metal slab or glass plate from a height of about 2 feet. If the cement is of the correct consistency, the ball will not crack nor will it flatten to less than half its original diameter.

9. Purpose of Test. ____ The test for time of setting is made to determine whether or not the cement will become hard at the time most desirable in actual construction. If it begins to set too soon, the crystallization of the particles will begin before the mortar or concrete is thoroughly tamped into place and further working of the mixture will tend to break up the crystals and to weaken the product. If, on the other hand, the cement sets too slowly, the material is more likely to suffer from exposure to heat, cold, or inclement weather; also, the progress of the work will be much delayed on account of the greater interval required between placing different sections, and the longer time the forms must be left in place. As the time of setting varies considerably with the amount of mixing water used, it is essential that every sample tested be brought exactly to normal consistency. The time of setting is also very appreciably affected by variations in the temperature and humidity of the air in which the test peices are kept during the period of setting, by the temperature of the mixing water, and the amount of kneading that the paste ~~required~~ receives. Standard practice requires that both the materials and the room in which the tests are made be at a tempertture of as near 21 degrees centigrade as practicable. Two froms of ap aratus are used to test the time of setting, namely, the Vicat needle and the Gillmore needles. In either case, the times are determined for both initial set and final set.

10. Specifications for Time of Setting. ___ The standard specifications stipulate that portland cement shall show initial set in not less than 60 minutes when the Gillmore needle is used, and shall develop final set in not more than 10 hours. It must be remembered that cement, mixed with an aggregate and with an excess of water in the field, will require from two to four times as long to set as the cement paste mixed with little water in the laboratory. Cement, therefore, showing an initial set at the expiration of 45 minutes with the Vicat needle or 60 minutes with the Gillmore needles, will generally not begin to set in actual concrete construction work in less than 1½ hours, which gives ample time for mixing and placing the materials; and cement setting in less than 10 hours by the test, will usually be quite hard in the work in 24 or, at most, in 36 hours, although the forms must be left in place on the work for a much longer time in order to obtain the required strength.

11. Soundness and Seasoning. ___ Soundness may be defined as the ability of cement to resist disintergration. Although a cement may at first show sufficient strength, it is dangerous to use it for construction purposes if there is a possibility of later disintergration. The most common cause of unsoundness in portland cement is an excess of free or uncombined lime, which crystallizes with great increase of volume and thus breaks up and destroys the bond of cement. This excess of lime may be due to incorrect proportioning, or to insufficient grinding of the raw materials, to underburning, or to failure to store for a sufficient length of time before use, such storing being called seasoning. A certain amount of seasoning is usually necessary, because almost every cement, no matter how well proportioned or burned it may be, will contain a small excess of lime which, when exposed to air, will absorb moisture and become inert.

12. Classification of Limes. ___ The two broad classes of limes are common lime, commercially called quicklime, and hydraulic lime.

Quicklimes are classified, according to their chemical composition, as follows: (a) high-calcium lime, containing at least 90 per cent. of calcium oxide; (b) calcium lime, containing from 85 to 90 per cent calcium oxide; (c) magnesium lime, containing from 85 to 90 per cent. calcium and magnesium oxide, of which 10 to 25 per cent. is magnesium oxide; (d) high-magnesium lime, containing not less than 85 per cent. calcium and magneseuim oxide, not less than 25 per cent. being magnesium oxide. Magnesium lime is also called dolomitic lime. There are two grades of quicklime, namely, selectedlime, which is well burned lime picked free from ashes, pieces of flint, clinker, and other foreign material; and run-of-kiln lime, which is a well burned lime without selection. Quicklime is shipped either as lump lime, the particles of which are of the sizes that come from the kiln, or pulverized lime, the particles of which are reduced to sizes that will pass a ¼ inch screen. There is also marketed what is called hydrated lime which is a fine dry powder resulting from the treatment of quicklime with water. Lump lime is usually sold in barrels of which there are two sizes. One size has a nominal weight of 200 pounds and a net weight of 185 pounds, and the other a nominal weight of 300 pounds and a net weight of 280 pounds. Loose material weighs 50 to 60 pounds per cubic foot or 75 to 80 pounds per bushel. Hydraulic lime contains such a large percentage of silicate, aluminate, or ferrate of lime that it will harden under water, usually in from 1 to 20 days. At the same time it contains so much calcium oxide that it will slake like quicklime when mixed with water. It is seldom used in the United States.

13. <u>Slaking Lime.</u> ___ When water is added to quicklime, a violent action, called slaking or slacking, occurs. The lumps break up, heat is generated, and a product, calcium hydroxide, is formed, which has an entirely different character from the original quicklime. Slaking is therefore a chemical process. When used in construction work, the lime is spread in a shallow, water-tight, wooden box, or on a wooden platform banked around the edges with sand, or is placed in a shallow bed of sand. The water is then added and the lime is thoroughly mixed with hoes during the slaking action, until uniform consistency of a thick paste is obtained. The product is called lime paste. The small quantity of sand that may enter into the lime during the process is unobjectionable, because a large amount of sand will be added later in making mortar. Enough water should be used and the mass thoroughly mixed so that the water will come in contact with all parts of the lime. If too little water is used or if the mixing is insufficient, some of the lumps become dry and are said to be burned in slaking. Burned lime makes mortar tough and non-plastic. An excess of water causes the slaking to proceed slowly and the resulting paste will be thin and watery. Such lime paste is spoken of as <u>drowned</u>. The amount of water required varies with the proportion of the lime. Some high-calcium limes may require as much as 60 gallons of water per 200-pound barrel to produce a paste; but for ordinary conditions the average amount needed to slake high-calcium lime is about 31 gallons per barrel or $1\frac{1}{3}$ pounds of water per pound of lime. The amount of water required to slake a dolomitic lime is considerably less, the maximum amount being about 30 gallons per barrel and the average 24 gallons per barrel or about 1 pound of water per pound of lime. The approximate quantity of water required to complete the slaking of a batch of quicklime should be applied by sprinkling before the mixing is begun. If cold water is added after slaking has commenced, the temperature of the mixture is lowered and the lime is caused to become granular and lumpy.

14. <u>Hydrated Lime.</u> ___ Hydrated lime results from the addition of an exact amount of water to a predetermined exact amount of lime. In producing hydrated lime, an excess quantity of water must be used above that required to combine chemically with the lime, because a certain quantity is driven off as steam by the heat generated in slaking. The quantity of water required is subject to wide variations, since it is dependent upon a number of conditions, such as temperature of the water, the quality of lime, and the dryness of the atmosphere. If too little water is used, some particles of lime will not have access to the water and these will not slake, but will be present in the finished hydrate, causing it to be unsound. Hydrated lime weighs 36 to 45 pounds per cubic foot, or 45 to 58 pounds per bushel. It is commonly sold in 100-pound sacks, having a volume of about $2\frac{1}{2}$ cubic feet. About equal weights of water and hydrated lime are required to make a paste. A 100-pound sack of hydrated lime gives about 2.3 cubic feet of paste of ordinary consistency.

15. Use of Hydrated Lime. — In general, a mortar that is made with hydrated lime and sand alone is not so strong as one made with portland cement and sand alone, but the addition of a limited quantity of hydrated lime to cement mortar does not weaken the mortar. However, an excessive amount of lime reduces the strength. There is considerable diversity of opinion as to the maximum percentage of hydrated lime allowable in portland cement mortar; many engineers maintain that 10 per cent. by weight is the limit. It is claimed that the addition of hydrated lime makes cement mortar more workable so that it can be more easily handled with a mason's trowel, and thus gives better bearing surface to the bricks. A further advantage is said to be increased ability of the lime-cement mortar to hold its moisture against the absorbing action of the bricks. Hydrated lime also makes wet concrete more plastic— more workable, and more readily cast or ~~m~~molded into shape. It gives fresh concrete the slipperiness required to enable it to slide down chutes, without the necessity of using so much water that the strength of the concrete is endangered and without the separation of the mortar from the coarse aggregate. It is claimed to increase the density of concrete, thus increasing the water-tightness and, to some extent, the durability. Steel embedded in concrete is protected by the addition of hydrated lime, because of the increased density and the neutralizing action of the lime on any corrosive acids that may be present. The possibility of underburning, overburning, or underslaking quicklime has led to its being largely replaced by hydrated lime.

16. Hardening of Lime. — Lime hardens by reason of the gradual absorption of carbon dioxide from the air. The carbon dioxide slowly changes the lime from the form of calcium hydrate to calcium carbonate, so that the final result is to restore the material to its original condition prior to burning; hardened lime mortar is practically limestone containing sand. To secure this result, however, all parts of the mortar must be readily accessible to dry air. If placed under water or in damp situations, of if excluded from contact with the air, lime mortars will not harden. Even in the interior of thin building walls of brick laid in lime mortar, the lime will be soft, crumbly, and sometimes even plastic after several years, although the edges of the mortar, where exposed, are perfectly hard. It is chiefly for this reason that lime mortars are no longer employed in important construction work, and have been superseded by cement mortars.

17. Fine Aggregates. — According to the Specifications for Concrete Aggregates of the American Society for Testing Materials, fine aggregate should consist of sand or other approved inert materials with similar characteristics, or a combination thereof, having hard, strong, durable particles. Also, the material must pass a 3/8 inch sieve and must be free from injurious amounts of dust, lumps, soft or flaky particles, shale, alkali, organic matter, or other deleterious substances.

18. Coarse Aggregate. ___ Coarse aggregate should consist of crushed stone, gravel, blast-furnace slag, or other approved inert materials with similar characteristics, or a combination thereof, having hard, strong, durable pieces free from adherent coatings. The material must not contain injurious amounts of soft, friable, thin, elongated, or laminated pieces, dust, lumps, shale, alkali, organic matter, or other deleterious substances. Not more than 10 per cent. by weight should pass a No. 4 sieve.

19. Sand. ___ The sand for mortar or concrete is usually obtained from natural deposits. It is not essential that the particles of sand be sharp, but the material must be clean and hard and the particles should preferably be graded in size from fine to coarse with the coarser sizes predominating. When sand is dug from a bank care should be taken to remove all the top soil first. Then, there will be no chance of loam sliding into the pit and mingling with the sand.

20. Stone. ___ The stone used as coarse aggregate is obtained by crushing rock in a rock crusher or by hand. Trap rocks, granites, and hard limestone and sandstones are satisfactory for use in concrete. Trap rocks, which are of igneous origin, are strong, tough, and durable, and are generally preferred for concrete that is to be subjected to abrasive wear, as in roads. The granites are usually hard and durable and are suitable for high-grade concrete. The limestones and sandstones vary greatly in quality; the hard limestones and compact sandstones make desirable aggregates, but the softer varieties should not be used in first-class concrete. Slate, unless of very solid and durable character, should be used only when no better material can be obtained as it is subject to disintegration. In general, differences in the hardness of sound particles of stone will affect the resistance of the concrete to wear but will not have a great influence on its compressive strength, as such particles of stone are considerably stronger than the hardened cement mortar that binds them together. Stone screenings can be used in place of sand, with satisfactory results, if they come from hard, durable rock, such as granite or trap rock, and if they are well graded, clean, and free from an excess of dust.

21. Influence of Aggregates on Quality of Concrete. ___ The strength, density, and general quality of concrete depend to a large extent on the aggregates. Even when the most careful attention is paid to the proportioning of the materials, and to the mixing and placing of the concrete, good results cannot be expected from poor aggregates. ~~In general~~ In general, the properties of the aggregates that influence the quality of concrete are: (1) the grading, or maximum and comparative sizes, of the particles; (2) the amounts and kinds of impurities in the aggregates; (3) the compressive strength, resistance to crushing, of the aggregates; (4) the durability of the aggregates, or their resistance to fire exposure, to weathering, and to wear. Before a material is used as an aggregate in concrete, it should be subjected to various tests.

22. Sampling of Sand and Gravel. ___ The two chief sources of supply of sand and gravel are non-commercial deposits and commercial sand and gravel plants. The term non-commercial deposit applies to any undeveloped sand and gravel deposit and also to any developed deposit where the material is not washed or screened. If such a deposit is worked as a bank or pit and has an open face, several samples should be taken by channeling the open face, care being taken not to include any of the material overlying the deposit that has fallen along the face from the top. Also, test pits should be sunk some distance back of and parallel to the face and several samples should be taken from these pits. The samples from the face and pits should be well mixed to form a composite sample. In the case of a non-commercial deposit that has no open face, the samples should be taken from test pits. If the various samples do not show radical differences in size of particles, color, etc., they may be mixed together to form a composite sample. Otherwise, each sample will require separate tests. Where possible, samples of sand should be taken when in a damp condition.

Samples of sand or gravel from commercial screening or washing plants should preferably be taken while the material is being loaded from bins or storage piles. However, if necessary, samples may be taken from a bin or pile or from cars or boats during unloading. Sand or gravel samples should be shipped in a tight box or closely woven bag.

23. Importance of Size and Shape of Particles. —— When the proportions of water, cement, and aggregates in a concrete or mortar mixture are fixed, the density of the mass and its plasticity or workability are determined in a large degree by the relative sizes of the particles of aggregate and the relative quantity of each size. In general, larger particles produce a more compact mass and there is less surface to be coated with cement paste. This is especially true of sand and therefore it is often advisable to ship a coarse sand a considerable distance rather than to use a local fine sand. Howeve, it does not follow that all the particles should be large. Generally, a well-grade aggregate produces a denser and more workable concrete than an aggregate whose particles are uniform in size, a sufficient quantity of fine grains being necessary to fill the voids or spaces between the larger pieces. The shape of aggregate articles, especially of coarse aggregate, has some effect on t the density and workabilty of concrete. Flat particles pack loosely and hence are less desirable than those of somewhat cubical shape. Also, round particles compact more firmly andmore readily than do angular particles.

24. Effects of Impurities. —— The principal impurities in aggregates are silt, clay loam, organic matter, talc, coal, mica, and alkali. The term silt is used to designate the fine earth material that a river carries in suspension for long distances and then deposits on its shores or bed. Silt may contain a variety of minerals depending on the nature of the land through which the river passes. The presence of a smallpercentage of silt, clay, or loam in a loose finely-divided condition in the aggregate is not usually harmful to concrete; on the contrary the fine materials, or loess, are advantageous in filling the spaces between larger particles. However, material in the form of a coatin on the particles of aggregate prevents the adhesion of the cement to the aggregate and weakens the concrete. A coating of vegetable or other organic matter on sand grains appears not only to prevent the cement from adhering but also to affect it chemically and to delay the setting process. The other impurities in aggregate are objectionable mainly because they are likely to disintegrate and thus cause disintegration of the concrete.

25. Test for Organic Impurities in Sand. —— The presence of injurious amounts of organic matter in sand determined approximately by the following test: A 12-ounce graduated prescription bottle is filled to the 4½-ounce mark with the sand to be tested, and a 3-percent. solution of sodium hydroxide (caustic soda) is added until the volume the sand and solution after shaking, amounts to 7 ounces. The mixture is then shaken thouroughly and left to stand for 24 hours. At the end of this period, the color of the clear liquid above the sand is observed. If the clear liquid is colorless, or has a light yellow color, the sand may be considered satisfactory as far organic impurities are concerned. But if a dark-colored solution, ranging from dark red to black, is obtained, the sand should be rejected, or used only after it has been put to the usual mortar-strength tests and found to give satisfactory results. A 3-per cent. solution of sodium hydroxide, made by dissolving 1 oz in enough water to make 32 fluid ounces, is sufficient to test five or six samples.

26. Resistance to Wear & Weather. __ Almost all commonly used rocks offer sufficient resistance to wear and weather to warrant their employment in concrete. Certain kinds of shale, however, crumble when exposed to the weather, and rock containing fragments of shale must therefore always be viewed with suspicion. For special purposes such as pavements, special wear-resisting aggregates are often required. However, since no suitable field tests for durability have been devised only aggregates that have been used successfully under similar conditions should be employed.

27. Kinds of Concrete and Mortar. __ Concrete may be classified as portland cement concrete, natural-cement concrete, alumina-cement concrete, bituminous concrete, etc., according to the character of the cementing material used in it. However, as portland cement is used so much more in concrete than other cements the term concrete is commonly used to denote portland-cement concrete, and this custom is followed here. Depending on the kind of cement used in it, mortar is known as portland-cement mortar or natural-cement mortar. Sometimes, a part of the cement in mortar is replaced by lime, and the mortar is then called lime-cement mortar. When lime is the only cementing material in the mortar, it is known as lime-mortar. All four kinds of mortar are used extensively and, unless it is clear from the circumstances which kind is meant, great confusion is liable to arise from failure to distinguish between them.

28. Proportioning of Concrete.__ Since sand and stone are cheaper than cement, it is desirable from an economic point of view to use as much sand and stone as possible in concrete in order to make the more costly cement go further. On the other hand, the strength and durability of concrete generally decrease when the amount of cement is decreased. Also, the proportions of the ingredients must be such that the fresh mixture will be sufficiently plastic and workable for the conditions under which it is to be placed in the forms. Therefore, it is necessary to limit the amounts of sand and stone used with a given quantity of cement paste. The limits vary with the nature of these materials and with the requirements of the work for which the concrete is to be used. The selection of the proper relative quantities of cement, sand, and stone is call proportioning of the concrete. The main problem in proportioning concrete or mortar is to obtain the most economical mixture of satisfactory quality with the available materials.

29. Durability of Concrete.__ Since concrete is made of durable materials, it will itself be durable if manufactured so as to resist attacks of disintegrating agencies. The chief of these is water. If water is allowed to enter the concrete intermittently, it tends to cause leaching out of certain desirable materials, and rusting of the reinforcing bars that may be in the concrete. Spalling of the masonry near the surface due to expansion of water while freezing is another injurious effect of that element. The solution of the problem of producing durable concrete, therefore, consists essentially in making the concrete impermeable or waterproof whenever it is to be subjected to severe exposure. Since the aggregates are impermeable, it is evident that any passage of water through the concrete must be through the hardened water-cement paste or through pores in the concrete created by improper proportioning. Waterproof concrete cantherefore be made by employing a paste that is itself impermeable, by using enough of the paste to fill the spaces between sand grains, and by having enough of the mortar to fill properly the spaces in the coarse aggregate. A relatively thick paste containing not more than 6½ gallons of water per sack of cement is considered fairly impermeable.

30. Strength. — Concrete is ordinarily used to resist loads in compression, so that its compressive strength is taken as the measure of quality. In reinforced work, however, its power of bonding or adhering to the reinforcing bars is also important. In pavements and heavy-duty floors, resistance to wear is a factor although concrete wears but little under rubber-tired traffic. Concrete is not usually expected to resist the tensile stresses due to bending in beams, steel reinforcing bars being provided for that purpose in the parts of the beam where such stresses exist. However, the concrete in beams is expected to resist part or all of the diagonal tension, which is a form of tension produced by the shearing forces in the beam. Sometimes concrete is also expected to resist some tension due to bending, as in a pavement slab without steel reinforcement where tensile stresses may exist in parts of the slab due to the bending that takes place when the foundation soil yields or is washed away. Fortunately the bond, wear resistance, shearing and tensile strength, and water-tightness of concrete are found to be affected by the same factors that influence its compressive strength, so that it is customary to design and test concrete on a basis of the compressive strength at the age of 28 days corresponding to the quality desired.

31. Workability. — An excellent conception of workable concrete is "an aggregate mass floated in the cement paste." In order to explain more fully the significance of this definition, it is perhaps easier to specify what a workable mix is not, than to say what it is. Thus, if the concrete is not harsh, that is, not difficult to place and finish, if it does not separate into layers of coarse aggregate and mortar, and if it can be puddled readily into the corners of the forms without leaving empty spaces or honeycomb, it is said to be workable. In other words, workable concrete should be free from harshness, segregation of the coarse aggregate, and honeycomb. The workability of a concrete mixture is commonly indicated by its consistency. Harshness may be caused by a deficiency of sand in the mix, that is, by an undersanded mix; by lack of fines in the sand; by the use of less mixing water than is required; or by an excessively lean mix due to the use of too little cement in proportion to the total amount of aggregate. Segregation of the coarse aggregate is almost invariably caused by the use of too much mixing water. The effect of excess water is aggravated by undersanding the mix and by allowing the plastic concrete to flow to place in the forms. Honeycomb may be cause d by undersanding or by the use of an extremely dry mix that is not compact by tamping. Excess workability may be obtained by employing too much sand or oversanding the mix, by using a very rich mixture, or by adding excess water. Oversanding reduces the strength of the concrete, and unnecessary richness increases the cost of the mixture; excess water results in a great decrease of strength and its use is to be condemned. Extremely rich mixtures that are too wet also tend to segregate. A workable mix may appear undersanded, but it can be easily finished with a trowel to present a smooth surface. In the undersanded mix there is not sufficient mortar to fill the spaces in the coarse aggregate, and the concrete will show hinoycomb in the forms. The oversanded mix is very plastic.

32. General Features. — The fundamental requirement of proportioning concrete mixtures are: (1) Each particle of fine aggregate must be coated with a film of cement paste and each particle of coarse aggregate must be coated with mortar; (2) all the voids or spaces between the individual grains must be filled. (3) the cement paste itself must be of the proper quality. Economy dictates that a given quantity of paste be used to bind together a maximum amount of aggregate.

33. Economy. The relation between strength and economy in proportioning concrete mixtures is important. It is possible to change proportions in three ways: (1) The mix may be made richer or leaner by using more or less cement; (2) it may be made wetter or dryer by using more or less water; or (3) the grading of aggregate may be made finer or coarser by using more or less sand in proportion to coarse aggregate. Changes in the mix affect the strength or economy of the concrete, as follows: Richer mixtures, drier consistencies, or coarser gradings produce higher strengths when other factors are kept constant because less mixing water per sack of cement is required. Leaner mixtures, drier consistencies, and coarser gradings produce more economical concrete of a given strength, because less cement in proportion to aggregate is necessary. Hence, economy is obtained in practice by using well-graded aggregates and the driest concrete mixtures that can be easily worked.

34. Coating Aggregate. Since the grains of sand and coarse aggregate remain entirely inert until coated with a film of cement paste, it is most important that there be at least sufficient cement paste to coat each grain of sand in the mortar, and sufficient mortar to coat each particle of coarse aggregate. Otherwise, the adhesion between the particles will be limited.

35. Filling Spaces. A mixture so proportioned that each particle of aggregate is coated with cement paste will be strong; but if the voids, or spaces between the particles, are not filled, it will not be dense, and the concrete will contain many pores and ducts through which water may enter the masonry. The ideal way of filling these spaces is so to proportion the mix that all the interstices between the larger pieces of aggregate are filled with smaller pieces, that the spaces between the smallest pieces of all are filled with cement paste, and that the cement paste itself is composed largely of solid matter, the water being combined chemically with the cement. Complete elimination of the voids is a condition rarely, if ever, attained in practice, but the more nearly this ideal is approached in any given case the more satisfactory the work will be. The use of sands that are too coarse for the mixture results in harsh mixes, difficulty in finishing, and porous concrete containing minute voids. A well-graded sand required less cement paste, and is more workable for a given amount of paste. A properly sanded concrete not only is more workable and plastic while fresh, but also when hardened contains less pore space and no honeycomb.

36. Quality of Paste. Minute voids in the concrete may be caused by excess mixing water in the cement paste. Less than half the water ordinarly used in mixing actually enters into combination with the cement to form hardened concrete. The excess remains scattered throughout the mass in the form of very small drops which in time evaporate or seep away, leaving a corresponding volume of pores. The amount of water used in mixing therefore affects not only the strength but also the density and permeability of the masonry; hence, water over the actual needs of the cement should be kept at a minimum.

37. Arbitrary Proportions. A common method of proportioning concrete mixtures is to specify the number of cubic feet of sand and coarse aggregate to be mixed with each sack of cement. When this practice is adopted, it is customary to use half as much sand as coarse aggregate. For ordinary purposes, the concrete mix consists of 1 bag of cement, which is assumed to have a volume of 1 cubic foot; 2 cubic feet of sand, measured damp and loose as it comes from the stock pile; and 4 cubic feet of coarse aggregate, also measured damp and loose. This is called a 1:2:4 mix. Mixtures in the proportion 1:1:2:, 1:1½:3, 1:2½: 5, and 1:3:6 are also used under certain conditions. For many years it has been assumed that the 28 day compressive strengths corresponding to these mixes would be as shown in Table 3, but the cements now used give much higher strengths.

38. Objections to Arbitrary Proportions. ___ Concrete mixtures designed on the basis of arbitrary proportions are defective for several important reasons. The method is obviously faulty because no account is taken of the water content. For example, a 1:2:4 mix may have a strength anywhere between 1,000 and 3,000 pounds per square inch, depending on the amount of water used in the mix. Again, the voids as measured in the loose aggregate do not indicate the amount of space to be filled in the concrete, as the pieces of coarse aggregate in concrete are forced apart by the sand grains and are therefore more widely separated; it is well known that a cubic yard of concrete is produced from less than a cubic yard of coarse aggregate. Furthermore, sand as measured damp and loose in the field is subject to bulking or fluffing apart of the particles, and the volume of bulked sand is not always sufficient to fill the voids, because the sand loses its bulking property when mixed in concrete. Hence, the volume of sand in the average mix should be more nearly two-thirds than one-half of the volume of coarse aggregate. The exact amount should be determined by trial.

39. Quantity of Mixing Water. ___ According to the water-cement-ratio law, the maximum quantity of mixing water per sack of cement is fixed by the specified strength of the concrete. The best known relation giving definite values for the water-cement ratio corresponding to the compressive strength of concrete at the age of 28 days was developed by Professor Duff A. ~~////~~ Abrams. This relation, expressed by Fig. 14, was derived from several thousand laboratory tests including a wide range of mixes, consistencies, and gradings. It is seen that the strength is decreased as the water per sack of cement is increased. For example, concrete whose compressive strength is 3,000 pounds per square inch may be expected to result from the use of not more than 6 gallons of mixing water per sack of cement, and 2,000 pound concrete should result if $7\frac{1}{2}$ gallons per sack are used.

40. Quality of Water. ___ The water used in mixing concrete should be clean, fresh and free from dirt or vegetable matter. Water containing even small quantities of acid may seriously injure the concrete. The presence of oil will result in slow setting and decreased strength. Salt is sometimes added to the water in mixing concrete for winter work, because salt lowers the freezing point of water and thereby delays the freezing of concrete. Salt so used is objectionable because it delays the hardening and decreases the strength and chemical compounds are formed that crystallize on the surface of the masonry as a whitish deposit called efflorescence, which is unsightly.

41. Relation of Time to Water-Cement Ratio. ___ It has been pointed out that the quantity of mixing water is a function of the strength of concrete, but it was assumed that all of the mixing water is retained in the concrete until the cement sets, usually in about 3 to 5 hours. If, however, some of the excess ~~//~~ mixing water is withdrawn before the cement sets and the concrete is allowed to settle and compact, the effect is practically the same as if the water had been omitted in the first place; in other words, the water-cement ratio at the time of set governs the quality of the concrete. Loss of water after that time does not compact the mass but merely leaves small air spaces in the hardened concrete.

42. Design of Mix. ___ The design of a concrete mixture consists of the selection of the water-cement ratio~~/~~ that corresponds to the desired strength, and then finding the most suitable combination of aggregate which will give the desired workability.

43. Job Conditions. — The strengths of different concrete mixtures having the same water-cement ratio might vary, depending on the character of the materials; the methods of mixing, placing, and curing the concrete; the temperature; etc. Usually the job strength will be greater than that taken from the Abrams curve, and it is customary to use this curve as a basis for design of mixtures. After the job is started, tests may be made to determine the effect of job conditions by finding out the strength obtained from a particular water-cement ratio. The point corresponding to the observed strength and the given water-cement ratio can be plotted on a diagram and a job curve may be drawn which will represent accurately the strength to be expected from any water-cement ratio used on that job.

44. Moisture in Aggregates. — Since most aggregates contain considerable amounts of moisture when delivered to the job, the volume of water to be added to a batch of concrete must be less by an equal amount to produce the desired water-cement ratio. For instance, suppose that the amount of water in a cubic foot of sand is 1/2 gallon and that in a cubic foot of coarse aggregate is 1/4 gallon. Then, in a 1:2 1/2: 4 field mix based on a water-cement ratio of 7 1/2 gallons, the amount of moisture per sack of cement in the sand is 2 1/2 x 1/2 equals 1 1/4 gallons, and in the coarse aggregate is 4 x 1/4 equals 1 gallon. Hence, the amount of water to be added to the mixture per sack of cement is 7 1/2 - 1 1/4 - 1 equals 5 1/4 gallons. A number of methods are employed to determine the moisture content of aggregates, the simplest of which is to dry out a small sample by air drying or heating and to observe the loss of weight of the sample. An ordinary postal scale is accurate enough for this determination if carefully handled. On the job, the moisture varies somewhat, and, in order to maintain a uniform water-cement ratio, the amounts of water added at the mixer need to be increased or reduced accordingly; however, these changes are not large, nor do they occur rapidly. The coarser the aggregate the less water it will carry.

45. Water absorbed by Aggregates. — Aggregates absorb water, some more than others. Approximate amounts of absorption by weight are: 1 per cent. of average sand, pebbles, or crushed limestone; 1/2 per cent. of trap rock or granite; 3 per cent. of average blast furnace slag. Light and porous aggregates absorb considerably more than these amounts, and should be tested by soaking a dry sample in water for 30 minutes, wiping the surface water from the particles, and observing the gain in weight. In practice, absorption is generally neglected, as it is small in amount and the quality of the concrete is improved by its effect. Aggregates do not usually absorb much water from the cement paste, but when exposed to the drying effect of the sun and the wind some aggregates may absorb large quantities. Evaporation from the concrete mass is also increased by sun and wind. To prevent shrinkage cracks in the fresh concrete from excessive loss of water, the aggregate may be wetted down before the concrete is mixed; in this way a uniformly moist aggregate is obtained, and it is easier to maintain a constant strength and consistency.

46. Desirable Proportions of Fine and Coarse Aggregates. __Owing to the wide variety of grading of aggregates used in concrete, no fixed rule of proportioning can be applied to all cases. For each job, and for each set of aggregates available, there is an ideal combination which should be determined according to one of the methods of proportioning that have been proposed by various engineers. The simplest method is by direct trial of the materials in an actual mix. Within the range of possible combinations there are three classifications of mix: (1) grossly oversanded, (2) workable, and (3) harsh or undersanded. For a grossly oversanded mix, excessive water is required, which reduces the strength of the mixture, and the concrete is likely to be porous. Decreasing the proportion of sand by replacing sand with coarse aggregate increases the strength, because less mixing water is required to lubricate the larger particles. Beyond a certain point, however, the sand is insufficient to fill the spaces in the coarse aggregate, and harshness results; since the harsh grading can only be made workable by flooding with water, the strength is reduced. An increase in the proportion of sand to coarse aggregate in a workable mix reduces the strength of the concrete, but such an increase in a harsh mix increases the strength. Lack of understanding of this basic fact if often responsible for employment of harsh mixes in concrete work. There is an erroneous notion among some concrete men that sand hurts concrete, whereas sand is less harmful than the excess water which is required for harsh mixes. Of course, grossly oversanded mixes are to be avoided, as either the strength or yield is reduced. With a fixed water-cement ratio and a given coarse aggregate, less of a fine sand than of a coarse sand will be required to obtain a specified consistency. More of a given sand will be required (1) when the maximum size of coarse aggregate is reduced; (2) when the particles of coarse aggregate are nearly all of one size; or (3) when the coarse aggregate consists of rough or angular particles rather than smooth, rounded pebbles. Hence, under a rigid specification for a mix known to be undersanded, the use of fine sand or a large size of coarse aggregate will relieve harshness.

47. Bulking Of Aggregates. __When moisture is added to dry sand, a film of water is formed on the surfaces of the particles, fluffing them apart. On account of the increase in volume due to fluffing and lack of compaction of the particles, which is known as bulking, the volume of damp loose sand used in a concrete mix may be only the equivalent of a much smaller volume of dry compacted sand. The amount of bulking depends on the percentage of moisture, the method of measurement, and the sizes of the sand grains. An amount of moisture equal to 1 per cent. of a given sand will cause the sand to bulk several per cent. The bulking increases rapidly until the amount of moisture is about 6 per cent. by weight, when the bulking may be as much as 20 or 25 per cent. Further additions of water tend to flood or pack the sand , decreasing the amount of bulking. When some 20 or thirty per cent. of water is added, the sand is completely flooded or inundated, and the volume of sand is approximately the same as when the sand is measured dry. Bulking of a given sand with a given moisture content is less when measuring container is large, because the sand is compacted somewhat under pressure. Even when the sand is compacted, however, the bulking is considerable. The finer the sand, the more it will bulk for a given moisture content and method of measurement. In the case of coarse aggregate, the effect of moisture in causing bulking is slight. Most of the so-called bulking in coarse aggregate which is usually not more than about 6 per cent is due to loose measurement and not to fluffing apart of the particles of the material.

48. Methods of Designing Mix. — When mixtures are designed according to the water-cement ratio principle, the quantity of mixing water per sack of cement is fixed by the required strength of the concrete, and it remains to find an economical combination of aggregates that will produce a workable mix with the relative volumes of cement and water. Concrete mixtures may be proportioned by trial, or on the basis of calculations made by any of several proposed methods. The trial method is usually preferred because of its simplicity and directness. According to this system of proportioning concrete, actual mixtures are made by using the proper water-cement paste and adding aggregates to obtain the best yield and workability. The trial mixes can be made either in the laboratory before the job is started or in the mixer on the job.

49. Method of Mixing. — Concrete is usually mixed in batches; that is, a batch composed of measured quantities of cement, water, and aggregates is assembled, mixed, and removed to the forms. A batch usually contains a whole number of full bags of cement, and is referred to as a one bag batch, a two bag batch, and so on, as the case may be.; the only fractions of bags that should be used are half bags, unless the cement is weighed. There are two methods of mixing concrete; namely, machine mixing and hand mixing. Practically all concrete, even for small jobs, is mixed by machine.

Machine mixers are of two classes, namely, batch mixers and continuous mixers. In the batch mixers, measured quantities of materials for a batch of concrete are fed into a power-driven revolving steel drum in which there are blades or buckets that handle the ingredients so as to mix them thoroughly. The mixing of each batch should continue from 1 to 1½ minutes after all the materials are in the mixer and the porpheral speed of the blades should be about 200 feet per minute, ~~,~~ or the drum should revolve ~~at~~ at a speed of 15 to 20 revolutions per minute. The batch is discharged by tilting the drum or by swinging a chute into a position where it will catch the plastic concrete and carry it out of the drum. Each batch is handled as a unit and no fresh material is added until all the mixed material has been removed from the drum.

In a continuous mixer raw materials are stored in a series of hoppers placed over one end of a semicircular trough in which revolves a shaft that has blades or shovels attached to it. The motive power is generally a gasoline engine or an electric motor. Dry materials are fed automatically from the hoppers into the trough, and are mixed and carried along by the blades to the discharged end, water biong added in transit. The distinctive feature of this type of mixer is that concrete is discharged continuously from one end of the trough. Batch mixers are used almost exclusively in engineering work, and the use of continuous mixers is confined to mixing mortar for brick and stone masonry and to mixing concrete for concrete products and small foundations. One objection to the continuous mixer is that the quality of the concrete is not uniform because variation in the moisture content of the aggregate or irregularity in the flow of cement from the hoppers is likely to prevent uniform proportioning. The other important objection is that the time of mixing is not under such control as in the batch mixers.

50. Time Required for Mixing. — Concrete should be mixed for a time sufficient to insure uniform distribution of particles and paste throughout the mass, eliminating dead spots, and to coat each particle with the paste. The strength of concrete increases with additional time of mixing, the increase being considerable during the first minute and less during each successive minute. Longer mixing also increases the plasticity of a batch of concrete and there is evidence to indicate that the water-tightness likewise is benefited. The exact point at which additional mixing ceases to be worth while depends on the class of work, size of mixer, type of mixer, and other conditions of the job. For instance, a large batch requires longer mixing than a smaller batch. A good rule is to continue mixing for one full minute after all materials are in the mixer before anything is withdrawn.

51. Measuring Materials. On many jobs, the aggregates are simply loaded into wheelbarrows and dumped into the mixer, each barrow being assumed to hold a certain volume of material. However, owing to the important effects of bulking and poor grading of aggregates, care should be taken, even when such a rough method is used, to load the wheelbarrows with nearly constant quantities. More uniform methods of measuring aggregates have now been developed. Batchers that measure proportions by volume give good results if bulking is compensated for properly. Nevertheless, since measurements by weight give absolutely uniform proportions and avoid the necessity of allowing for bulking, weight batchers are coming into more general use. Even when the aggregates are weighed, however, it is necessary to take into account changes in the moisture content of the aggregate so as to provide the proper amount of mixing water. Many concrete mixers are equipped with water-measuring tanks that can be set to give a constant volume of water for each batch ofconcrete. These tanks can be accurately ddjusted, and the setting locked by the inspector. Some of them have been improved to prevent leakage of water into the mixer while the concrete is being discharged, and to insure constant amounts of water even when the mixer is on sloping ground. Accurate measurement of both sand and water can be accomplished by the use of a device called an inundator, in which the bulking of the sand is destroyed by measuring it in a saturated condition.

52. Transporting Concrete. Concrete is hauled from the mixer to the forms in carts or trucks, or it is raised on a hoisting tower and made to flow into the forms through chutes or spouts. Wahtever method of transportation is employed, precautions should be taken to prevent segregation of the coarse aggregate from the mortar. Unduly wet mixes cannot be transported far without settling of the larger particles to the bottom, leaving the fines and water at the surface. On the other hand, sufficiently plastic mixes can be hauled without segregation, and can in many cases be chuted with good results. Concrete mixed at a central plant and transported for a long distance to the forms requires a rather dry consistency to prevent segregation during hauling. Concrete transported in this way should not be placed directly in the forms but should be dumped on a platform and rehandled into the work.

53. Placing Concrete. Concrete should be deposited as nearly as possible in its final position, as flowing in the forms tends toward separation of the water and fines from the rest of the mass. Entrapped air should be permitted to escape by tamping or puddling the wet concrete in the forms. Spading the concrete next to the forms will make surface finishing easier. Accumulation of water on the surface of concrete during placing should be avoided by proper proportioning; if, however, such a layer of water is unavoidably formed, it should be drained off. When depostied in forms, the concrete should have a temperature of not more than 120 degrees F. nor less than 40 degrees, a good average temperature being 60 to 70 degrees.

54. Surface Finish. Concrete surfaces are susceptible to a variety of finishes. In ordinary work, as in walls, piers, and abutments, a satisfactory surface is obtained by using smooth and tight forms which are held rigidly in place and by spading the concrete carefully next to the forms. Where desired, a smoother finish may be given to the concrete surface by wetting it with water as soon as the forms are removed and rubbing it with a brick of coarse carborundum or of mortar. There are various tools for giving a concrete surface the appearance of stonework. A sand blast is sometimes used when the expense involved is small compared to the cost of the structure. If the forms are removed about 12 hours after the concrete has been placed, the surface mortar can be brushed off and the broken stone exposed by means of a steel or stiff rattan brush. When the concrete surface is finished by means of a steel trowel, care should be taken to avoid overtroweling, as it draws cement and fines to the surface and causes surface cracks or checking. Ordinarily a wooden float will give best results. In two-course work, such as floors, stucco, etc., the finish coat should not be richer nor made with finer sand than the mortar of the concrete underneath, as the richer or finer mixes have a higher rate of expansion and contraction, and cracks are likely to result.

55. Curing. The hardening of concrete is caused by a chemical reaction between water and the cement particles, which is known as hydration of the cement. Therefore, although an excess of mixing water weakens the cement paste in concrete, it is desirable to prevent concrete from drying out too quickly. The process of keeping concrete damp and at a favorable temperature for a certain length of time to insure complete hardening is called curing the concrete. No part of the process of concrete manufacture has a better effect on its quality than curing. In a typical case under observation, the strength was increased 50 per cent. by keeping the concrete damp 7 days and 100 per cent by damp curing for 3 weeks. Watertightness is improved in a similar manner, as the combination of water with cement results in greater density and less pore space. Continuous damp curing is a major factor in preventing checking and dusting of floors, pavement, etc., especially if the moisture is applied soon enough to prevent the surface from drying out and shrinking before the concrete has hardened. Since concrete as mixed contains an excess of water over that required for hydration, the problem of curing becomes that of keeping the entrained water inside the concrete. If the surface could be effectually sealed, perfect curing would result. Present methods of sealing, however, appear to lack effectiveness in preventing evaporation of water from the hardened concrete. The most reliable method of curing concrete appears to be the application of water to exposed surfaces by sprinkling or ponding, or by covering the surface with damp sand, earth, straw, canvas, or other suitable material. This method has the advantage of giving excellent curing conditions at the surface, the most important place. Exposed surfaces should be protected from drying out for at least 7 days, a longer period being advisable, if practicable. Vertical surfaces may be protected by leaving forms on as long as possible, or by hangings of canvas or burlap kept sprinkled.

56. High-Early-Strength Concretes. Quick-hardening concrete is used in special construction, such as pavement repairs, high-speed building construction, and cold weather work. The chief high-early-strength concretes are produced (1) by means of high-alumina cement or special high-grade portland cement mixes, (2) by the use of special mixes of ordinary portland cement, and (3) by the addition of accelerating admixtures. High-early-strength concrete may be made with ordinary portland cement by applying the following directions: (1) Use a very rich mix, containing about 50 per cent more cement than is usual, and a dry consistency; a low water cement ratio is then possible. (2) Mix the concrete from 3 to 5 minutes. (3) Keep the temperature of the concrete as high as practicable. (4) Tamp the concrete or compact it by other means. It is also important that a temperature of not less than 70 degrees F. be maintained during the curing period. The accelerating admixture that is generally employed is calcium chloride. It should be tried out with the particular brand of portland cement used in the work, as it does not give favorable reaction with all cements.

57. Cold Weather Work. The rate of hardening of concrete is increased at temperatures higher than normal, whereas for temperatures lower than 40 degrees Fahrenheit the process of combination of water and cement practically ceases. In freezing weather it is important to maintain the temperature of the concrete above 50 degrees until it has hardened sufficiently to resist freezing. Common practice fixes the time limit at the age when the concrete develops one fourth of its 28 day strength; this stage of hardening is ordinarily reached in 5 days. Protection is usually accomplished by canvas covers, salamanders, or steam heat inside the structure, or similar means, care being taken to keep the air from drying out. Manure should not be used because it contains acids that injure the cement. Aggregates and mixing water may be heated before bing used in the mixture provided the heat is sufficient to spall the aggregates nor cause caking or flash set of the cement. A safe maximum temperature for fresh concrete at the mixer is 140 degrees F. To insure a certain temperature of the concrete when deposited in the forms, the temperature at the mixer should be about 20 degrees higher. Accelerators such as calcium chloride are sometimes used in cold weather work with good results. Their function is to hasten the hardening process and reduce the required time for heating and protecting the concrete. The curing period during which protection is necessary is also materially shortened when special concretes that develop high early strength are employed.

58. Joining New Concrete with Old. New and old concrete can be joined only with great difficulty, and the strength of such a connection is always uncertain. The joining is best done by chipping and cutting away the old surface, thoroughly cleaning it of all dust, dirt, and loose particles, saturating it with water, painting it with a cement grout paint mixed to the consistency of thick cream, and then, while this coating is fresh, immediately placing the new concrete. As cement begins to harden within a very short time after combining with water, the grout paint should be applied only a short distance in davance of the work of depositing. The cleaning can be done very thoroughly by means of wire brooms and water under pressure.

59. Depositing Concrete Under Water. Three different methods have been successfully used for depositing concrete under water; namely, (1) cloth bags, (2) buckets, and (3) a tremie, or spout. The buckets are open at the top, and are provided with doors at the bottom which open downwards. The bucket should be completely filled and lowered slowly. It should not be discharged until it rests on the surface to be concreted, and should be withdrawn slowly until clear of the concrete. In some cases large bags of loose weave have been filled with concrete and lowered to position in the water; the bags were left in place with expectation that sufficient of the cement would seep through the loosely woven material to cement the bags together. In other cases, smaller bags of closer weave with an opening in the bottom have been used. The tremie is a water-tight tube sufficiently large to permit the free flow on concrete through it. There is usually a hopper at its upper end to better receive the concrete. Its lower end is temporarily closed and it is lowered into position, resting on the surface to be concreted. Newly mixed concrete is then fed into the hopper above the water until the tremie is full of concrete and the concrete flows out at the bottom. After a while the flow will cease because the concrete piles up around the bottom of the tremie, choking off the stream. The apparatus is then lifted a few inches and when the flow starts anew the tremie is slowly swung over the area to be concreted, the hopper being always kept full. If the tube is raised too high, the concrete escapes all at once and the tremie must then be withdrawn and refilled. If the concrete is too wet, the charge in the tremie is liable to run out, while if too dry, the concrete may block the passage through the tube. In placing concrete under water, extreme care must be used to prevent the water from washing the cement away from the mixture. To avoid this, the concrete should not be permitted to fall through the water, and no current of water should strike the concrete before it hardens. It is therefore necessary to surround the space to be concreted with a water-tight form. Concrete for use under water should contain more cement than that used for work on dry land, and the amount of fine and coarse aggregate combined should never exceed six parts to one of portland cement. Hand mixing should not be permitted. The concrete should be deposited continuously and with sufficient rapidity to insure bonding of the successive layers. The top surface should be kept nearly level. While being deposited, the concrete should be disturbed as little as possible to prevent the formation of laitance, which is a chalky deposit of low strength composed of extremely fine particles that separate from the freshly laid concrete and collect on the top surface.

60. Waterproofing Concrete. All concretes absorb water to a greater or less degree. Therefore, they not only permit dampness to penetrate a building, but also tend to permit destruction by frost. Portland-cement concrete may best be made almost impermeable by using aggregates that have been carefully graded and by adding hydrated lime. If further protection is desired, a common method is to apply a wash of waterproofing to the finished surface, which fills the voids in the mortar and also forms a coating. For this purpose paraffin can be used; solutions of soap and alum applied alternately combine to form insoluble acids and also give good results. These coatings are easily and cheaply applied but the objections to their use are that they are liable to crack when the masonry cracks and they are liable to separate from the masonry and peel off. A more effective method is to coat the hardened concrete with an elastic membrane such as bitumen or coal-tar pitch reinforced with felt or fabric. These membranes are expensive and, as they are susceptible to injury from the outside, they are usually protected by a covering of brick or concrete which increases the cost.

61. Volume Changes In Hardening Concrete. ___Concrete contracts upon initial drying out in air, to the extent of about .05 per cent, or 6 inch in 100 feet. The amount of this shrinkage does not appear to be affected by the water-cement ratio or by the extent of curing, but it is increased by a greater cement content or by an excess of fine dust in the aggregate. If concrete is rewetted after drying out, it expands to the extent of about 04 per cent., but it contracts about the same amount upon subsequent drying out. On the other hand, if concrete is cured damp for a period of several weeks from the time it is placed, it expands about ¼ inch in 100 feet.

62. Expansion and Contraction of Concrete. ___Nearly all materials expand slightly as they become heated and contract while cooling, and concrete follows this law. The generally accepted value of the coefficient of expansion of average concrete due to temperature is .0000055 for 1 degree Fahrenheit; this amounts to a change in length of .0066 inch in 100 feet for each degree of change in temperature.

63. Colored Concrete.___The natural color of portland cement concrete may be varied to meet architectural requirements by the additon of suitable tinting materials. Because of the chemical reaction that takes place between cement and organic pigments, nothing but mineral pigments should be used to color concrete. Too large a proportion of pigment tends to impair the strength of the cement, and, in general, it is found that an amount of pigment exceeding 5 per cent. of the weight of the cement should not be used. Coloring matter should always be thoroughly mixed with the dry cement before water is added. Weighing of cement as well as coloring matter is preferable to measuring by volume, since weighing is more exact, and ingredients must always be exactly proportioned to prevent variations in the tint.

64. Proportions of Cement Mortar. ___ Portland cement mortars are made in proportions varying from 1:1½ to 1: 6 . The richer mixtures are used for facing of concrete blocks and other ornamental concrete products, for waterproofing surfaces, for wearing and finishing coats on floors and pavements, etc., the 1:2 mixture being usually employed for such purposes. The leaner mixtures are used for rough work, filling, backing, etc., but should never be employed where either much strength or much density is desired. The number of parts of sand in natural cement mortar is commonly made one less than in portland cement mortar used for the same purpose, although a decrease of about 2 parts of sand is necessary to produce the same strength. For example, where a 1: 3 portland cement mortar would be used, a 1: 2 natural cement mortar is substituted; however, the strength of a 1: 2 natural cement mortar is only equivalent to that of a 1: 4 portland cement mortar. Cement mortar mixtures are usually provided by arbitrary proportions, sufficient water being added to give a desired workability or consistency. However, when mortar of a certain strength is required it is best to proportion it by the trial method in the same manner as for a concrete mixture. For general purposes, the mortar should be of a plastic consistency — firm enough to stand at a considerable angle, yet soft enough to work easily. The consistency of the mortar should vary with the materials used and with the conditions to be met.

65.
Mixing. — A complete and uniform mixture of the separate ingredients of cement mortar is best obtained by means of mechanical contrivances; but, since mechanical mixers are rather expensive to install and operate, it is only where large quantities of material can be used in a short time that such appliances can be employed to advantage. Mortar that is to be mixed by hand is prepared on a platform or in a mortar box. The sand is first measured by means of a bottomless barrel, or, better, by means of a low, square, bottomless box with handles on the sides and of such a size that it will give the correct quantity of sand. After the box is filled, the sand is struck off level, the box lifted up, and the sand spread in a low, flat pile. The required quantity of cement is then placed on the sand and spread evenly over it. The pile is then turned over and mixed with shovels, the materials being worked over not less than four times. After this operation, the dry mixture is formed into a ring, or crater, and the water intended to be used is poured into the center. The material from the sides of the basin is then shoveled into the center until the water is entirely absorbed, after which the pile is worked again with shovels and hoes until the mixture is uniform and in a plastic condition. In mixing, the mortar should be completely turned over not less than four times dry and from four to six times after the water has been added. Another method of mixing, where a mortar box is used, is to gather the mixed dry materials at one end of the box and pour in the water at the other end, drawing the mixture into the water with a hoe in a little at a time, and hoeing until plastic consistency is obtained.

66. Strength of Cement Mortar. — The structural value of a mortar depends on its resistance to tensile, compressive, tranverse, and shearing stresses, and also on its adhesion to inert surfaces, its resistance to impact and abrasion, etc. In masonry construction, although mortar is generally subjected only to compressive stress, it is also at times called on to withstand tensile, transverse, and shearing stresses. There is no definitely fixed ratio between the strengths of mortar subjected to these different stresses, but there is a close relation between them; hence, it may be assumed that if a mortar shows either abnormally high or low strength in any one test, it will develop proportionally high or low values when tested under other stresses. In practice, therefore, the tensile or compressive strength of mortar is commonly determined and its resistance to other forms of stress is estimated from these results. The tensile or compressive strength of mortar varies with the character and proportions of its ingredients, with its consistency and age, and with many other factors. A mortar that is to be used in important construction should show tensile or compressive strengths not less than those of a mortar made of the same cement mixed with the same proportion of standard Ottawa sand and possessing the same consistency.

67. Useful Data on Cement Mortar. — The following brief sentences summarize the important points to be remembered concerning the cement mortar.

1. The stength of a mortar depends primarly on the percentage of cement in the mixture, and on the volume of mixing water per sack of cement.

2. The most economical moratr for a specified strength is obtained by using a well graded sand and the driest mixture that will be workable.

3. The best sand is, in general, that which will produce the smallest volume of martar when mixed with the cement in the required proportions.

4. Sharpness of sand grains is of slight importance.

5. Coarse sand produces stronger mortar than fine sand.

6. Fine sand requires more water than coarse sand to produce a mortar

is less dense.

7. Mixtures of fine sand and coarse, or of sand and screenings, often produce better mortar than either material alone.

8. Imputities in sand, such as vegetable loam, even in a minute quantities, may injure the strength of the mortar.

9. The average weight of portland cement mortar in proportions 1: 2½ is 135 pounds per cubic foot.

68. Use of Lime Mortar. __Lime mortar is employed chiefly for brickwork of the second class such as is commonly used in the walls of smaller buildings, and its ~~chief~~ use is continually decreasing as that of cement mortar is increasing. It is absolutely unsuitable for any important construction, because it has little strength and is porous. It cannot be used in damp or wet situations, nor should it be laid in cold weather; the mortar is materially weakened by alternate freezing and thawing before it has set. Moreover, since it hardens by the action of dry air, only the exterior of lime mortar ever becomes fully hardened. The mixtures employed vary from 1: 2½ to 1: 5. Building laws in many municipalities require the use of a 1: 3 mixture, and for most materials this proportion will be found satisfactory.

69. Mixing Lime Mortar. __In mixing lime mortar, a bed of sand is made in a mortar box and the lime is distributed as evenly as possible over it, both the lime and the sand being first measured according to the specified proportions. The lime is then slaked by pouring on water, after which it should be covered with a layer of sand, or preferably a tarpaulin, to retain the vapor given off while the lime is undergoing the chemical reaction of slaking. Additional sand is then used, if necessary until the mortar attains the proper proportions. Care should be taken to add just the proper quantity of water to slake the lime completely to a paste. If too much water is used, the mortar will never attain its proper strength, while if too little is used at first, and more is added during the process of slaking, the lime will have a tendency to chill, thereby injuring its setting and hardening properties. Rather than make up small batches it is considered better practice to make lime mortar in large quantities and to keep it standing in bulk so that it can be used as needed.

City Engineer.